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NASA CR- 144823

AOIPS WATER RESOURCES DATA MANAGEMENT SYSTEM

(NASA-CR-144823) AOIPS WATER RESOURCES DATA
MANAGEMENT SYSTEM Final Report, Dec. 1975 -
Aug. 1976 (Earth Satellite Corp.) 535 p HC
A15/MF A01

N77-14567

CSCL 08H

Uncclas

G3/43 58896

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September 1976

Final Report for Period December 1975 -- August 1976

Prepared for

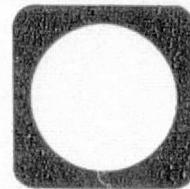
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TECHNICAL REPORT STANDARD TITLE PAGE

| | | | |
|--|---|--|------------|
| 1. Report No. Final Report | 2. Government Accession No. 933-91512-0001(1C) | 3. Recipient's Catalog No. | |
| 4. Title and Subtitle AOIPS WATER RESOURCES DATA MANAGEMENT SYSTEM | | 5. Report Date September 1976 | |
| 7. Author(s) Earl S. Merritt, Robert L. Shotwell Michael C. Place, Nathaniel J. Belknap | | 6. Performing Organization Code | |
| 9. Performing Organization Name and Address Earth Satellite Corporation 7222 47th St. (Chevy Chase) Washington D.C. 20015 | | 8. Performing Organization Report No. | |
| 12. Sponsoring Agency Name and Address Goddard Space Flight Center Greenbelt Road Greenbelt, Maryland 20771 | | 10. Work Unit No. | |
| | | 11. Contract or Grant No. | |
| | | 13. Type of Report and Period Covered Type III Final Report Dec. 75- Aug. 1976 | |
| | | 14. Sponsoring Agency Code | |
| 15. Supplementary Notes | | | |
| 16. Abstract A geocoded data management system applicable for hydrological applications was designed for implementation on the AOIPS hardware at Goddard Space Flight Center. The emphasis throughout the contract was to demonstrate the utility of the Atmospheric and Oceanographic Information Processing System (AOIPS) for hydrological applications. Within that context, the geocoded hydrology data management system was designed to take advantage of the interactive capability of the AOIPS hardware. Portions of the Water Resource Data Management System which best demonstrate the interactive nature of the hydrology data management system were implemented on the AOIPS. A hydrological case study was prepared using all data supplied by Goddard Space Flight Center for the Bear River watershed located in northwest Utah, southeast Idaho, and western Wyoming. | | | |
| 17. Key Words (Selected by Author(s)) Hydrology, AOIPS, Geocoded Database Bear River Watershed Interactive Computer System | | 18. Distribution Statement | |
| 19. Security Classif. (of this report) None | 20. Security Classif. (of this page) None | 21. No. of Pages | 22. Price* |

*For sale by the Clearinghouse for Federal Scientific and Technical Information, Springfield, Virginia 22151.

ACKNOWLEDGEMENTS

This report was prepared under the technical direction of Mr. Earl S. Merritt. Major technical contributions were made by Michael Place, Robert Shotwell, and Nathaniel Belknap. The illustrative materials have been prepared by Edmund Schantz and Luis DeMendoza.

Special thanks should go to Mr. Peter Van Wie of Goddard Space Flight Center for his support in the conduct of the contract. The authors would also like to thank Mr. Philip Pease and Mr. John Dalton of Goddard Space Flight Center for their assistance in the scheduling of time on AOIPS and help in learning to use the AOIPS hardware.

PREFACE

Objective

Earth Satellite Corporation, working under NASA Goddard Space Flight Center Contract No. NAS5-22894, has designed a geocoded data management system applicable for hydrological analysis. The central features accommodated by the system design include:

1. Ability to process a variety of data types related to hydrological parameters;
2. Ability to store and retrieve data within a common framework for all data types;
3. Ability to analyze spatial and temporal relationships between hydrologically related parameters through video displays and overlays;
4. Ability to drive existing main-frame hydrologic models from outputs of the system.

The emphasis throughout the contract was to demonstrate the utility of the Atmospheric and Oceanographic Information Processing System (AOIPS) for hydrological applications. Within that context, the geocoded hydrology data management system was designed to take advantage of the interactive capability of AOIPS hardware. Portions of the Water Resource Data Management System which best demonstrate the interactive nature of the hydrology data management system were implemented on the AOIPS. A hydrological case study was prepared using all data supplied by GSFC for the Bear River watershed located in northwest Utah, southeast Idaho, and western Wyoming.

Scope of Work

Five distinct activities were performed under this contract:

1. System definition - Hydrology Applications Scenario was defined to demonstrate the utility of AOIPS to hydrologists using the Bear River watershed as a case study area (approximately 5% of total effort).
2. Applications Software Implementation - Approximately 15 applications software modules were converted for use on AOIPS hardware (approximately 40% of total effort).
3. Data Base Design - A geocoded Water Resources Data Management System was designed specifically for implementation on AOIPS hardware (approximately 10% of total effort).
4. Water Resources Data Management System Implementation - A portion of the geocoded hydrology application data management system was implemented in order to demonstrate the hydrology applications scenario (approximately 35% of total effort).
5. System Documentation (approximately 10% of total effort) - Software and system documentation was prepared for:
 - a. Hydrology scenario
 - b. Implemented software
 - c. Data base file structure
 - d. Geocoded Hydrology Data Management System
 - e. Implementation User Guide

Conclusions

Previous experience by EarthSat personnel in a variety of application areas has demonstrated the utility of storing application specific

data in a geocoded reference system. Work performed under this contract has shown the increased advantages of directly tying the geocoded data base to an interactive display capability such as that available on AOIPS.

In specific applications of hydrology it should be pointed out that the existing hydrology models consider as their "smallest unit of information" the watershed basin or sub-basin area. Sub-basin areas may in fact cover a large geographic area displaying a variety of terrain, vegetation covered patterns, soil types, etc. The natural resolution of various remotely sensed data is frequently much smaller than the sub-basin level. It is therefore possible to study a watershed area at a level much smaller than that currently used by the principal hydrological model. This capability to study a basin or a watershed on a variety of spatial levels promises to be a great aid to the application scientists.

Summary of Recommendations

As a result of the work performed under contract NAS5-22894 Earth Satellite Corporation recommends:

1. The implementation of the geocoded Water Resources Applications Data Management System be completed with emphasis directed towards the river forecast problem.
2. Potential hydrology application users be strongly encouraged to use the existing portions of the system to gain hands-on experience with their own hydrology problems.

Additionally, Earth Satellite scientists believe that while the specific details of this system design are currently directed toward the hydrology applications area the general design concept used here is

applicable, and in fact directly transferable, to many other application areas. The geocoded data base is developed for the hydrology applications which are structurally similar to the agrometeorological data files used by the AGMET yield modeling systems developed at EarthSat. The interactive nature of the hydrology systems is certainly applicable to many other application areas including agronomy, forestry, and range land management to name only a few. EarthSat therefore recommends a consideration be given to broadening the scope of the hydrology activities to include other discipline areas.

TABLE OF CONTENTS

| | <u>Page</u> |
|--|-------------|
| ACKNOWLEDGEMENTS | ii |
| PREFACE | iii |
| Objective | iii |
| Scope of Work | iv |
| Conclusions | iv |
| Summary of Recommendations | v |
| TABLE OF CONTENTS | vii |
| LIST OF FIGURES | xvi |
| LIST OF TABLES | xvii |
| 1.0 INTRODUCTION | 1-1 |
| 2.0 HYDROLOGY APPLICATIONS ON AOIPS | 2-1 |
| 2.1 Existing Hydrology Models | 2-2 |
| 2.1.1 NWSRFS Model | 2-3 |
| 2.1.2 SSARR | 2-4 |
| 2.1.3 HEC-1 | 2-5 |
| 2.2 Hydrology Model Data Requirements | 2-5 |
| 2.3 Data Requirements Satisfied By Remotely Sensed Data | 2-6 |
| 2.4 AOIPS Capability as Applied to the Needs of the Hydrology Application | 2-7 |
| 3.0 HYDROLOGY SCENARIO | 3-1 |
| 3.1 System Overview | 3-2 |
| 3.2 Hydrology Scenario Components | 3-4 |
| 3.3 System Capabilities | 3-10 |

| | <u>Page</u> |
|--|-------------|
| 3.4 WMO Grid | 3-11 |
| 3.5 Importance of the Geocoded Grid System Concept | 3-12 |
| 4.0 HYDROLOGY SCENARIO DOCUMENTATION | 4-1 |
| 4.1 System Generation Documentation | 4-1 |
| 4.1.1 System Environment | 4-1 |
| 4.1.2 File Structure | 4-2 |
| 4.1.3 System Generation | 4-8 |
| 4.2 User's Guide Documentation | 4-11 |
| 4.2.1 Methods of Data Insertion | 4-11 |
| 4.2.1.1 Precipitation Data | 4-13 |
| 4.2.1.2 LANDSAT Classification Data | 4-13 |
| 4.2.2 Methods of Data Retrieval | 4-14 |
| 5.0 AOIPS HYDROLOGY DEMONSTRATION | 5-1 |
| 5.1 Introduction | 5-2 |
| 5.2 Hydrology Applications on AOIPS | 5-3 |
| 5.2.1 Existing Hydrology Models | 5-3 |
| 5.2.2 Hydrology Model Data Requirements | 5-4 |
| 5.2.3 Data Requirements Satisfied By Remotely Sensed Data | 5-5 |
| 5.3 Hydrology Scenario | 5-7 |
| 5.3.1 System Overview | 5-7 |
| 5.3.2 System Capabilities | 5-11 |
| 5.3.3 AOIPS Capability as Applied to the Needs of the Hydrology Application | 5-11 |
| 5.4 AOIPS Hydrology Software Demonstration | 5-13 |

| | <u>Page</u> |
|---|-------------|
| 5.5 Conclusions and Recommendations | 5-31 |
| 5.5.1 Conclusions | 5-31 |
| 5.5.2 Recommendations | 5-31 |
| APPENDIX A: Software Documentation | |
| 1.0 OVERVIEW | A-1 |
| 2.0 GENERAL PURPOSE SUBROUTINES | A-2 |
| 2.1 OPEN | A-2 |
| 2.2 OPENMT | A-5 |
| 2.3 OPENRD | A-9 |
| 2.4 OPENIC | A-10 |
| 2.5 READER | A-12 |
| 2.6 WRITER | A-14 |
| 2.7 REREAD | A-15 |
| 2.8 RWND | A-17 |
| 2.9 EOF | A-19 |
| 2.10 WAIT | A-21 |
| 2.11 SET | A-23 |
| 2.12 SKIP | A-25 |
| 2.13 UNPK | A-26 |
| 2.14 BDSW | A-28 |
| 2.15 BDSTAT | A-30 |
| 2.16 GTWND | A-35 |
| 3.0 APPLICATIONS SOFTWARE | A-36 |
| 3.1 GRAY | A-36 |
| 3.1.1 MAIN | A-36 |

| | <u>Page</u> |
|--|-------------|
| 3.1.2 INIT | A-37 |
| 3.1.3 ISCAN | A-38 |
| 3.1.4 GRYSCL | A-39 |
| 3.1.5 SLICER | A-40 |
| 3.1.6 HISEQL | A-40 |
| 3.1.7 PICT | A-41 |
| 3.1.8 LITTON | A-42 |
| 3.1.9 User's Guide | A-42 |
| 3.1.10 IMAGE-100 Modifications | A-43 |
| 3.2 ENLRG | A-52 |
| 3.2.1 MAIN | A-52 |
| 3.2.2 SCAN | A-54 |
| 3.2.3 HISTR | A-54 |
| 3.2.4 EXPAND | A-55 |
| 3.2.5 XPDBYT | A-57 |
| 3.2.6 User's Guide | A-57 |
| 3.3 REDUCE | A-64 |
| 3.3.1 MAIN | A-64 |
| 3.3.2 SCAN | A-65 |
| 3.3.3 HISTR | A-65 |
| 3.3.4 REDUCE | A-65 |
| 3.3.5 XPDBYT | A-66 |
| 3.3.6 User's Guide | A-67 |
| 3.4 PSPECT | A-70 |
| 3.4.1 MAIN | A-70 |

| | <u>Page</u> |
|------------------------------|-------------|
| 3.4.2 NNODE | A-72 |
| 3.4.3 CONECT | A-72 |
| 3.4.4 DETIJ | A-73 |
| 3.4.5 IN21 | A-73 |
| 3.4.6 OUT22 | A-74 |
| 3.4.7 User's Guide | A-74 |
| 3.5 INTERP | A-81 |
| 3.6 BSTBND | A-83 |
| 3.6.1 MAIN | A-83 |
| 3.6.2 COVAR | A-84 |
| 3.6.3 GETEIG | A-85 |
| 3.6.4 EIGEN | A-86 |
| 3.6.5 LOC | A-87 |
| 3.6.6 COMBIN | A-88 |
| 3.6.7 User's Guide | A-88 |
| 3.7 GRID | A-96 |
| 3.8 POLYGO | A-96 |
| 3.8.1 MAIN | A-96 |
| 3.8.2 GETPNT | A-97 |
| 3.8.3 BORDER | A-98 |
| 3.8.4 SORT | A-99 |
| 3.8.5 FILLIN | A-100 |
| 3.8.6 INSERT | A-103 |
| 3.8.7 FILL | A-104 |
| 3.8.8 User's Guide | A-105 |

| | <u>Page</u> |
|--|-------------|
| 3.9 SHADE | A-116 |
| 3.9.1 MAIN | A-116 |
| 3.9.2 GETSET | A-118 |
| 3.9.3 AUTOST | A-119 |
| 3.9.4 CRUNCH | A-120 |
| 3.9.5 User's Guide | A-121 |
| 3.10 EDGE | A-125 |
| 3.10.1 MAIN | A-125 |
| 3.10.2 SETKER | A-126 |
| 3.10.3 RDKER | A-127 |
| 3.10.4 CONVLT | A-127 |
| 3.10.5 ROTATE | A-128 |
| 3.10.6 STRETCH | A-129 |
| 3.10.7 STORIT | A-130 |
| 3.10.8 User's Guide | A-130 |
| 3.11 HHIST | A-139 |
| 3.12 REGIST | A-141 |
| 3.13 CONTOURS | A-141 |
| 3.14 LINE | A-141 |
| 3.15 COMBINE | A-141 |
| 4.0 DATA MANAGEMENT SOFTWARE | A-142 |
| 4.1 CINDEX | A-142 |
| 4.2 POLYB | A-145 |
| 4.2.1 MAIN | A-145 |
| 4.2.2 GETPNT | A-147 |

| | <u>Page</u> |
|------------------------------|-------------|
| 4.2.3 INSERT | A-148 |
| 4.2.4 User's Guide | A-150 |
| 4.3 CDATA | A-153 |
| 4.4 NBASIN | A-156 |
| 4.5 OPENPT | A-158 |
| 4.5.1 OPENB | A-158 |
| 4.5.2 OPENPT | A-159 |
| 4.5.3 OPENAR | A-160 |
| 4.5.4 OPENDY | A-160 |
| 4.6 PLYDMP | A-165 |
| 4.7 PLYRD | A-169 |
| 4.7.1 MAIN | A-169 |
| 4.7.2 OPENPG | A-169 |
| 4.7.3 STASH | A-171 |
| 4.7.4 EXPAND | A-172 |
| 4.7.5 IJREG | A-173 |
| 4.7.6 User's Guide | A-173 |
| 4.8 DISPLAY | A-177 |
| 4.8.1 MAIN | A-177 |
| 4.8.2 EXTRACT | A-178 |
| 4.8.3 FLTEXT | A-179 |
| 4.8.4 User's Guide | A-179 |
| 4.9 ERTS200 | A-183 |
| 4.9.1 MAIN | A-183 |
| 4.9.2 AFYNE | A-184 |
| 4.9.3 GRID | A-187 |

| | <u>Page</u> |
|---|-------------|
| 4.9.4 AGGR | A-188 |
| 4.9.5 LIMITS | A-189 |
| 4.9.6 FLIP | A-190 |
| 4.9.7 XYREG | A-190 |
| 4.9.8 FILL200 | A-191 |
| 4.9.9 INS200 | A-191 |
| 4.9.10 MATINV | A-192 |
| 4.9.11 User's Guide | A-192 |
| APPENDIX B: The 1980 Hydrologic Forecast Situation | |
| SUMMARY | B-1 |
| INTRODUCTION | B-3 |
| THE CYCLE | B-3 |
| CURRENT FORECASTS | B-5 |
| CURRENT FORECAST PROCEDURES | B-5 |
| ERRORS IN FORECASTING | B-6 |
| FORECAST RESEARCH ACTIVITIES | B-11 |
| MODELING APPLICATIONS OF FORECASTING ACTIVITY | B-13 |
| PROJECTED FORECASTING TECHNIQUES | B-18 |
| CLOUD COVER | B-23 |
| FOREST COVER LIMITATIONS | B-24 |
| SENSOR RESOLUTION LIMITATIONS | B-26 |
| SPATIAL RESOLUTION LIMITATIONS | B-26 |
| SPECTRAL RESOLUTION FACTORS | B-27 |
| FREQUENCY OF COVERAGE REQUIREMENTS | B-27 |
| SOCIO-ECONOMIC FACTORS RELEVANT TO THE PROJECTED FORECAST | |
| ACTIVITY | B-28 |

| | <u>Page</u> |
|--|-------------|
| CONCLUSION | B-29 |
| INTERACTIVE COMPUTER SYSTEMS FOR FUTURE HYDROLOGICAL APPLICATIONS | B-31 |
| SCENARIO OVERVIEW | B-32 |
| CHANNEL ROUTING | B-38 |
| FLOW ROUTING PROCEDURE | B-38 |
| CONSTANT LAG | B-38 |
| VARIABLE LAG | B-39 |
| ATTENUATION BY CHANNEL STORAGE | B-40 |
| FOOTNOTES | B-46 |

LIST OF FIGURES

| | <u>Page</u> |
|--|-------------|
| FIGURE 3-1 Hydrology Scenario | 3-5 |
| FIGURE 3-2 Hydrology Data Management System | 3-8 |
| FIGURE 4-1 Data Flow Through the AOIPS Hydrology Data Management System | 4-12 |
| FIGURE 5-1 Hydrology Scenario Design | 5-10 |
| FIGURE 5-2 Bear River Basin | 5-15 |
| FIGURE 5-3 Full Frame LANDSAT of Bear River Basin | 5-17 |
| FIGURE 5-4 Bear River Watershed Sub-basins | 5-19 |
| FIGURE 5-5 LANDSAT 200 Meter Sampled Image Around Bear Lake . . . | 5-21 |
| FIGURE 5-6 LANDSAT Multispectral Classification Results | 5-23 |
| FIGURE 5-7 SMS Image Over Bear Lake | 5-25 |
| FIGURE 5-8 SMS Image Over Bear Lake | 5-26 |
| FIGURE 5-9 Raw Image Display of Topographic Data | 5-28 |
| FIGURE 5-10 Perspective Plot Generated from Topographic Data . . . | 5-30 |
| FIGURE B-1 Diagrammatic Representation of the Hydrology Cycle . . | B-4 |
| FIGURE B-2 Network Chart for Estimating the Error in Watershed Average Rainfall Amounts | B-7 |
| FIGURE B-3 SSARR Model Algorithm for Streamflow Forecasting . . . | B-15 |
| FIGURE B-4 Forest Cover Regions in the Western United States . . | B-25 |
| FIGURE B-5 Flow Chart of Soil Moisture Accounting Portion of the National Weather Service River Forecasting System . . | B-34 |
| FIGURE B-6 Channel and Flow Routing Procedures | B-35 |

LIST OF TABLES

| | <u>Page</u> |
|--|-------------|
| TABLE 4-1 Label Record | 4-3 |
| TABLE 4-2 Index Records | 4-4 |
| TABLE 4-3 Archive Data Record | 4-6 |
| TABLE 4-4 Daily Records | 4-7 |
| TABLE B-1 Forecast Error Distribution | B-9 |
| TABLE B-2 Major Agency Research Activity Allied to Forecasting . . | B-10 |
| TABLE B-3 Current and Projected Forecasting Techniques | B-20 |
| TABLE B-4 Hydrometeorological Satellite Assisted Water Management Systems | B-21 |
| TABLE B-5 Coverage Frequency Extremes for Critical Forecast Variables | B-28 |

1.0 INTRODUCTION

The application of interactive computer systems to hydrology is being accelerated by two rapidly advancing technologies; i.e., hydrological simulation models, and remote sensing. Simulation models provide a "real world" mathematical view of various hydrological processes, while remote sensing offers an opportunity to monitor hydrological processes in a here-to-fore impossible manner. Application of these two technologies in an interactive system permits daily application of the most basic of scientific study approaches; i.e., "observe, predict, observe."

NASA's Goddard Space Flight Center (GSFC) has under development an interactive information processing system which has been termed AOIPS (Atmospheric and Oceanographic Information Processing System). AOIPS will permit rapid processing and manipulation of remote sensor data, ground-based observational data, and historical data, and will furthermore permit more active operation of available hydrological simulation models using information derived from these sources.

In order to exercise the capabilities inherent in the AOIPS and to provide an effective demonstration of its application, a hydrology demonstration has been defined which, while obviously incomplete, will permit potential users to sit at a console and operate on a set of real data in a real and complex basin.

The central focus of the hydrology demonstration is a geocoded data management system. The geocoded data base will accommodate a variety of types of input data:

1. Remotely sensed data:

- a. LANDSAT/MSS
- b. SMS/VISSR

- c. NIMBUS/ESMR
- 2. Data products derived from space sensor data:
 - a. Snow cover maps
 - b. Water extent maps
 - c. Rainfall maps
 - d. Soil moisture maps
 - e. Land use maps
 - f. Flood plain boundary maps
- 3. Ground truth data:
 - a. Topographic ground elevation data
 - b. USGS stream flow records
 - c. Ground water level records
 - d. Reservoir storage volume data
 - e. Soil Conservation Service (SCS) snow water equivalent data
 - f. SCS predicted stream flow data
 - g. U.S. Army Corps of Engineers flood prone area maps

In fact the geocoded data bases are designed to allow the application user to specify whatever data types he has potential interest in.

The geocoded data management system demonstrated in the hydrology scenario allows for a wide range of processing of the data stored in the geocoded data bases. Processing options include:

- a. Change of scale
- b. MSS band combinations
- c. Contrast enhancement
- d. Edge enhancement

- e. Registration of preprocessed multiple data sources
- f. Logical union and intersection of polygon overlays

While it would be impossible to actually demonstrate all of these capabilities within the hydrology demonstration, the software capability to perform these algorithms has been provided under this contract.

The geocoded data management system allows the user to process, store, and retrieve parameters suitable for input to hydrological models which could be operational on AOIPS in the future. Information stored in the data bases may be retrieved and displayed on the color CRT of the AOIPS GE Image 100. Color displays may be generated from multiple data sources by operator console commands. The data may be accessed at several levels of resolution, including:

1. Natural resolution of the data source
2. One square mile cell resolution
3. Sub-basin or basin level resolution

The hydrology demonstration will be performed using real data supplied by GSFC for the Bear River watershed located in northwest Utah, southwest Idaho, and western Wyoming.

The hydrology report begins by discussing the existing hydrology models currently in use today. The data management system provided as part of the hydrology demonstration is then discussed in Chapter 3. Chapter 4 together with Appendix A provides a user documentation of the data management system along with the various file structures and software-related information. Chapter 5 provides a copy of the hydrology demonstration booklet prepared for use during the hydrology demonstration. As such, much of the information presented in the first four chapters of this final report is summarized in Chapter 5.

Two appendices are provided as part of this final report. Appendix A contains all of the software system documentation necessary to use the software delivered under this contract. Appendix B provides a copy of the hydrology overview prepared early in the work of this contract.

2.0 HYDROLOGY APPLICATIONS ON AOIPS

The river forecast problem posed itself as an ideal hydrological application for AOIPS. The problem addresses questions of information needs for urban flood forecasting and seasonal water run-off forecasting which in turn are used for public disaster warnings, hydroelectric power management, and irrigation management. Additionally, the problem contains many elements which could best be served by remote sensing and interactive computer processing. Finally it is noted that components of the river forecast problem are of joint interest to other application scientists. Meteorology, agronomy, and rangeland management have interests in precipitation estimates and soil moisture budgeting, as well as the calculation of potential evapotranspiration.

The design of the system to demonstrate the hydrology application on AOIPS was constructed within the context of existing models and currently available data sources. An effort was made to design the system to supply the needs of the most complex models currently in use. It would be hoped that this design concept would accommodate most new input elements required by future models; it certainly should supply all of the needed elements of less complex existing models.

The contract activities began by having EarthSat hydrologists/meteorologists^{1/} prepare the 1980 Hydrologic Forecast situation: Where the major deficiencies will exist and how they may be improved. This forecast reviewed the current state-of-the-art for hydrology and projected a 1980 state-of-the-art. This forecast provided the perspective under which the AOIPS hydrology application work proceeded.

^{1/}

Mr. Earl S. Merritt, Director, Food Resource Group. Mr. Richard Stanley, Staff Hydrologist (now with Far East Foundation).

Several of the major hydrology models currently in use will be briefly discussed in this chapter. The data requirements of these models will then be discussed in the light of how remotely sensed data may satisfy these requirements.

2.1 Existing Hydrology Models

The purpose of hydrology models is to assess the effect of a rain or other event on the water flow rate within a watershed basin. The model itself is a mathematical abstraction and provides the researcher with the ability to examine the consequences of decisions such as channel modification or to predict the effects of snowmelt. In either case, the variations in stream flow can be estimated and these data used to make policy decisions.

Each of the three models discussed in this section has two basic components:

1. Estimation of stream or system inflow within each sub-basin of the watershed;
2. Combination of these inputs to predict unit hydrographic readings at selected points within the stream system.

Each of the models estimates mean precipitation over the basin area from weighted ground station data. These data are combined to estimate the area mean precipitation for the current time interval or event. Combined with parameters describing the ground condition of the basin (e.g. current soil moisture content, soil type, land use, slope of terrain, etc.), it is possible to estimate the amount of ground run-off entering the stream system from that sub-basin. The stream or river system is a mathematical network, each compo-

ment of which possesses certain characteristics, such as storage, through-put time, elevation, etc. Inflow from each sub-basin is entered into the network at that time interval. A certain amount of that component's inflow will "pass-through" and enter the next downstream element. This process is repeated for each interval over all network elements and the aggregate effects measured at hydrographs placed at various locations within the stream network. These hydrographic data can then be analyzed to measure the effects of decisions or events.

2.1.1 NWSRFS Model

The National Weather Service River Forecast System (NWSRFS) was developed by the Hydrologic Research Laboratory of NOAA to estimate river hydrographic (stage) levels. Estimation of mean basin precipitation is performed by averaging the estimated precipitation for all grid points within the basin. A fine mesh or grid is superimposed over the basin and the assigned precipitation for each grid point is the weighted sum of the nearest reporting station in each quadrant surrounding the grid point. The land phase of the hydrologic model estimates evapotranspiration potential (ETP) and actual evapotranspiration (ET). These and other calculated variables estimate the soil moisture status and infiltration. Remaining waters were accounted for as either surface run-off or interflow. These, combined with ground water storage, provide inflow to the channel system.

The channel system is segmented into a network of reaches or storage areas. The amount of water in each reach

is a function of the inflow and outflow, not only from the sub-basin precipitation but from upstream regions. The change in storage during an interval is proportional to the average interval outflow. The coefficients and constants used in the routing and transfer equations are determined using observed data. Station precipitation and hydrographic readings for specific events are used to optimize the model for the specific watershed being studied.

2.1.2 SSARR

The Streamflow Synthesis and Reservoir Regulation model was developed by the Corp of Engineers to provide both operational river forecasting and management data as well as analyses needed for planning and design. The model is similar in many respects to the NWSRFS model discussed in Section 2.1.1. Specifically, basin precipitation is estimated from point observations. Additionally, the basic soil moisture parameters were estimated using current soil moisture levels, infiltration, rainfall amount, and so on. The stream inflow from surface, sub-surface, and base flow are time-tagged from the occurrence of the event. The stream routing relations are based on the same assumptions as the NWSRFS model. The major difference arises in the inclusion of snowmelt parameters. Operational constraints for the Pacific Northwest require the annual snowmelt to be monitored. Consequently, temperature, elevation, total snowpack, and radiation models are used to estimate run-off from snowmelt since this is not directly measured and in some areas provides the major portion of stream inflow.

2.1.3 HEC-1

The HEC-1 flood hydrograph package was developed by the Corp of Engineers to estimate the flood potential of a basin system. Consequently, it is applicable only to the single storm event and cannot be used to monitor the basin over time. While the precipitation estimation is the same as the other two models discussed above, the land phase is much more general, its sole purpose being to estimate run-off or stream inflow. The stream system routing mathematics is essentially identical to the SSARR model.

2.2 Hydrology Model Data Recommendations

Each of the models discussed in Section 2.1 has certain basic data requirements necessary to run it. In each case historic streamflows on station precipitation data are combined with static regional data to optimize specific coefficients for the model. Variables including land use, soils, impervious area, and vegetation cover are used to estimate parameters such as infiltration indices, basin time lags, etc. The historic data are input and the model is iteratively run until the prediction closest to observed data is obtained.

Operationally it is necessary to initialize the model with the status of the stream system. Parameters such as current streamflow rate at each hydrograph can be used. Similarly, for those models with a snow melt component, an estimate must be made of the snow pack status. Meteorological parameters are required several times a day to provide accurate estimates of the environmental factors.

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Specifically, precipitation estimates, temperature, wind, and radiation measurements are used to estimate evapotranspiration potential, mean precipitation, etc. These data are in turn used to modify the hydrologic status of the basin system within the framework of the models discussed above.

2.3 Data Requirements Satisfied By Remotely Sensed Data

Many of the data requirements for the existing hydrologic models can be supplied through the uses of remotely sensed data. Land use, soils, and vegetation information can be obtained using high resolution imagery. Additionally, sufficiently detailed land use data can be used to supply ground and vegetation cover information. From these data, initial estimates of infiltration indices and other soils surface parameters can be inferred.

Probably the greatest potential contributions of remote sensing are in the areas of precipitation and soil moisture estimation and area monitoring.. As currently implemented, each model estimates area precipitation based on observations at selected stations in the basin area. In the case of the NWSRFS discussed in Section 2.1, an estimate of point precipitation is made by a weighted sum of surrounding station observations. The weights used are proportional to the distance between the points in the observing station network. Given a relatively dense network of reporting stations this approach works reasonably well; however, in relatively inaccessible regions or in areas where the network is sparse, the accuracy of this technique is poor. One solution which can be used is to estimate the location and amount of precipitation from meteorological satellite data such as SMS visible and infrared imagery. These

data, obtained repetitively during the day, can be analyzed as to cloud type and brightness. These descriptors are then used to empirically estimate precipitation from that cloud mass.

Similarly, it is possible to use satellite imagery to monitor the snow pack. Area measurements of snow cover can be combined with topological data to estimate snowmelt potential. As snowmelt begins, satellite data can be used to monitor the melt process. These observations can be used to refine the operational model estimates and used in flood prediction models.

2.4 AOIPS Capability as Applied to the Needs of the Hydrology

Application

In the initial phases of the contract work, the usefulness of AOIPS to the hydrology application science appeared to be principally as a system to process raw data into a form acceptable for use by existing hydrology models. For example, the AOIPS system could be used to transfer SMS data from its raw form (digital imagery) to a form accepted by NWSRFS (mean basin precipitation). As EarthSat scientists gained experience in using AOIPS hardware, it became apparent that this important function may not ultimately be the principal use of AOIPS by hydrologists. The interactive capability to display, overlay, and, in general, to analyze digital data, tied directly to a geocoded data base which contained all hydrologically-related parameters, promises to be an extremely powerful tool for the research hydrologist to use in improving existing models and in developing new models. This marriage of display capabilities with geocoded information data files contain-

ing a variety of data types provides the researcher with the capability to easily investigate spatial and temporal relationships between observed phenomena. The interactive nature of the system will allow the user to query the information files for specific types of events, and "track" the events as they are processed by the AOIPS system and then eventually by the large river forecast hydrology models. This type of application user "hands-on" experience should result in valuable improvements in the understanding of hydrology-related phenomena.

3.0 HYDROLOGY SCENARIO

During the initial system definition phases of this contract it was decided that the system design would be prepared in light of the ultimate capability which AOIPS could provide to the hydrology user. As such, the system demonstration prepared under this contract would represent a single component of a larger system. The advantages of this design concept are:

1. The ultimate and complete utility of the system is apparent from the start;
2. The system design remains flexible and versatile so that as yet unknown or unexpected application problems may be easily accommodated;
3. The system becomes usable to the application scientist long before it is fully completed;
4. Implementation of design features may be prioritized so that the most important features to the application scientists are implemented first;
5. Complete implementation of the hydrology applications system may be accomplished within the framework proposed in the design, thus minimizing any reprogramming effort on future contracts.

In the first section of this chapter, an overview of the entire system is provided, the components of the hydrology file are discussed, and capabilities of both the present and future potential systems are finally described.

3.1 System Overview

Earth Satellite Corporation hydrologists began by preparing an AOIPS hydrology scenario. Within this work, a number of currently existing major hydrology models were studied with particular regard to input data requirements. Emphasis was placed on identifying those hydrology parameters which are currently available (or possibly available in the future) from remotely sensed data. The hydrology applications data processing system was designed with the intent of being capable of processing all of the input data requirements needed by the most sophisticated hydrology models in existence today. This type of design allows all less sophisticated hydrology model data requirements to be provided as a subset of a complete system.

Two immediate questions have to be resolved concerning the system design. First, since the system required storing geocoded information a particular grid system had to be adopted. Second, since input data at a variety of scales and projections would have to be processed, a "standard resolution element" had to be established; staff hydrologists agreed that the World Meteorological Organization (WMO) grid system provided an excellent grid framework for storing the geocoded information. The WMO grid is well defined for all parts of the globe and is easily adapted to different size resolution elements.

The standard cell resolution element was defined to be one square mile. The one square mile cell was agreed upon because it provided a good compromise between the natural resolution sizes of the various types of input data. The problem existed, however,

that the smallest resolution unit accepted by any of the hydrology models was the sub-basin unit. Depending upon application, a sub-basin may be as small as a single stream basin or as large as an entire river basin. The concept of dual data files at different resolutions emerged as the natural solution of this problem. The first data file stored at the one square mile cell resolution served as an intermediate step between the natural resolution of the input data and the final required resolution of the sub-basin level. In this case, a sub-basin is defined as a specific aggregation of any number of one square mile cells. At this point, the fundamental design features of the information processing system had been defined:

1. All initial processing of input data would be performed at whatever unit resolution was most logical for that particular data type;
2. Initially processed data would be converted and stored at the intermediate one square mile cell level. This may require aggregating data in the case of LANDSAT/MSS-derived inputs, or spatial interpolation of data as in the case of point weather station data;
3. The one square mile cell data would be aggregated upward to the sub-basin level with the sub-basin being defined by the application user.

In addition to considering the spatial properties of data storage, it was necessary to also consider the temporal properties of the data to be processed. As noted in the AOIPS hydrology scenario paper (see Appendix B), it is necessary to provide the

hydrological models with slowly varying data such as soil type, land use cover, and porosity maps as well as the rapidly varying data such as maximum and minimum temperatures and precipitation. Since it would be inefficient to maintain all of the slowly varying data within the same data file as the rapidly varying data, it was decided to maintain two types of data files:

1. An archive file with all of the slowly varying data.
2. A daily file with only information related to a specific observation date.

In total, there would be four separate data files maintained on the hydrology data management system on AOIPS:

1. Cell Archive - containing only slowly varying information entered at the one square mile cell level.
2. Cell Daily - containing only daily inputs entered at the one square mile cell level.
3. Basin Archive - containing all slowly varying information aggregated up to the basin level from the sub-level.
4. Basin Daily - containing all daily inputs aggregated up to the basin level from the cell level.

In reality, the only difference between the archive data files and the daily data files is in the meaning associated with the numbers stored in the data files and the frequency with which the files are updated with new information. The same file structure is used for both sets of files.

3.2 Hydrology Scenario Components

Figure 3.1 shows the overall flow of the entire geocoded hydrology data management system. As is indicated on Figure 3.1,

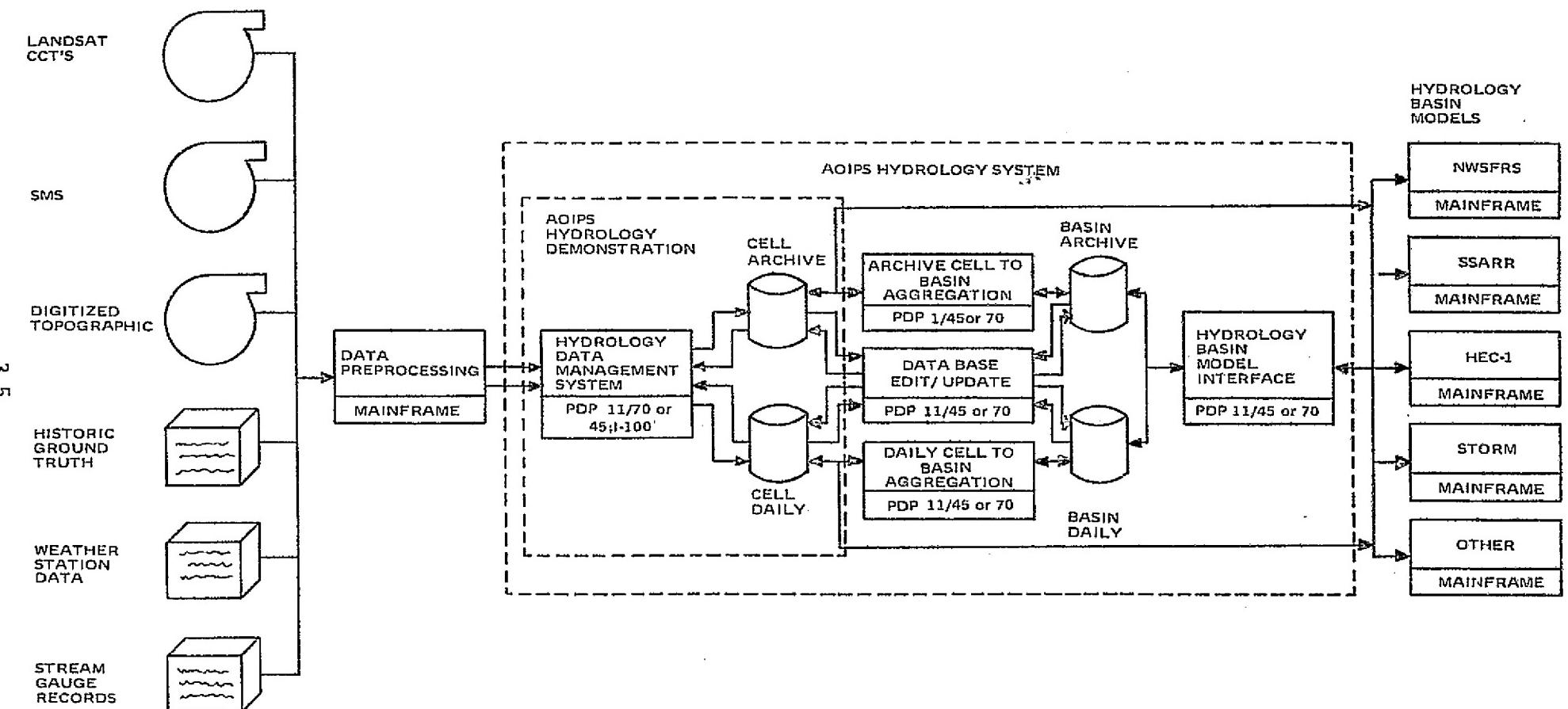


FIGURE 3-1 HYDROLOGY SCENARIO

the entire system includes the AOIPS hardware as the central data processor and manager with interfaces on both input and output to a main-frame computer system.

Depending upon data type, the original data enters the AOIPS system either directly or after some specialized pre-processing (block A on Figure 3.1). Data pre-processing may be performed for a variety of purposes:

1. Reformating original data;
2. Changing data projections;
3. Extracting data windows of interest.

Basically, any operation not requiring an interactive capability designed to reduce, transform, or edit the original data may be performed at the pre-processing step.

After completion of any necessary data preprocessing, the data enters the Hydrology Data Management System on AOIPS (block B on Figure 3.1). It is at this point where most of the interactive data processing is performed. Implementation of those portions of the AOIPS hydrology system to be demonstrated under this contract were therefore selected from this activity. Four primary functions were performed by the AOIPS Data Management System:

1. Data reduction - Any necessary data reductions or transformations are performed to prepare the data for entry into the geocoded cell level data base use.
2. Spatial registration - Data is registered to the geocoded data base grid system through the use of ground control points.

3. Data entry - Data items are entered into the geocoded cell level data base use. Where necessary data is aggregated or interpolated to the one-mile cell level prior to entry.
4. Cell data preview - Cell level data file entries may be edited, displayed, overlayed, and updated.

Figure 3.2 shows the expanded view of the Hydrology Data Management System. The type of processing performed at the data reduction step is seen to be very "data type specific." New data types may be easily incorporated to the hydrology system by simply providing additional specialized data processing options at this point. The geocoded data files are sufficiently general to allow the user to specify what information is to be stored in the files once it reached the "data entry stage."

The final function performed by the Hydrology Data Management System is the cell level preview and edit function. Any data which has been stored in the geocoded data files may be retrieved and displayed on the one square mile cell level. Execution time options are available to allow the users to selectively display information within the data files.

Block C on Figure 3.1, shows the next step in the processing of data by the AOIPS Hydrology Scenario. Once data has been entered into either the archive or daily file at the one square mile cell level it must be aggregated up to the sub-basin level. Data aggregation would be performed using a variety of algorithms depending on the type of data being aggregated. The basin archive and basin daily files would then contain all of the data necessary to drive the main frame hydrology models. The aggregated data could also be edited and updated at the basin level.

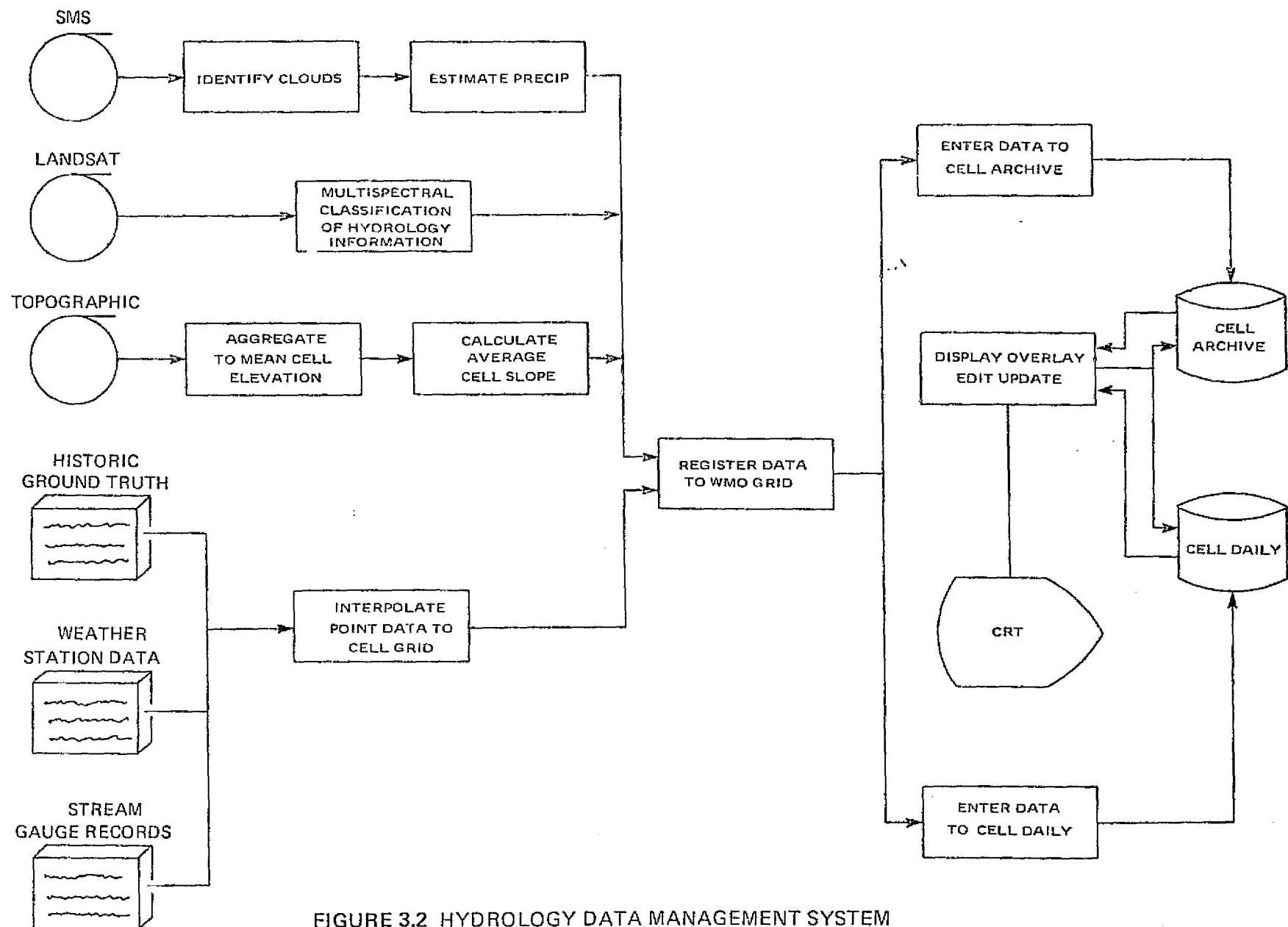


FIGURE 3.2 HYDROLOGY DATA MANAGEMENT SYSTEM

Block D on Figure 3.1, would provide the final interface to the hydrology basin models. The only function performed by the basin model interface would be to format the data contained within the basin archive and basin daily files to a form acceptable to the particular hydrology model being used.

As an example of how the AOIPS Water Resources Data Management System could be used to process data, consider the following sequence of processing steps which might be applied to input SMS data tapes:

- 1) Extract SMS window of interest from the master data tape (Block A on Figure 3-1).
- 2) Use METPACK to identify ground control points (Block A).
- 3) Display SMS window on the Image-100 and locate clouds with the cursor (Block B).
- 4) Identify cloud types and make precipitation estimates (Block B).
- 5) Enter cloud data and precipitation estimates into the Cell Daily Database (Block B).
- 6) Use the spatial distribution of the cloud cell data to drive the net solar radiation calculation in the Over Land Phase of the Hydrology Basin models.
- 7) Use the precipitation estimates for each cell to drive the potential evapotranspiration calculation in the Over Land Phase of the Hydrology Basin models.
- 8) Store the results of the Over Land Phase calculation performed by the Hydrology Basin models back in the Cell Daily Database (Block B).
- 9) Aggregate the Over Land Phase results to the basin level and store in the Basin Daily Database (Block C-1).

- 10) Aggregate the precipitation estimates to the basin level and store in the Basin Daily Database (Block C-1).
- 11) Format the basin level data from the Basin Daily Database for use by the Channel Routing Phase of the Hydrology Basin models (Block D).
--

3.3 System Capabilities

Several important features of this design should be noted:

1. New types of information may be easily accommodated with a minimum amount of new programming.
2. Users have an opportunity to study the impact of hydrological events at four different levels: original input data resolution, one square mile cell resolution, basin resolution, and finally at the hydrology model "resolution."
3. New models may be tested by entering "pseudo" data at any appropriate point in the system.
4. The hydrology basin model interface allows the user to easily compare the results of different hydrology basin models.

As mentioned earlier the implementation of the AOIPS hydrology system for the demonstration was directed towards portions of the Hydrology Data Management System. The ability to process SMS data, LANDSAT data, and topographic data was developed to demonstrate those features of the system. Additionally, the ability to generate the cell level data files as well as to enter, retrieve, display, and overlay information from those files was developed for

the demonstration. The ability to process other data types including meteorological weather station data, historical ground truth data, stream gauge records and other point source data have not yet been developed.

3.4 WMO Grid

A grid mesh system which is frequently used in operational meteorology was selected for this study as offering a convenient system in which to manage the computations and data manipulations. While some aspects of the grid definition might conveniently have been modified for the current application, this was not done, thereby allowing for future expansion to a global scale and remaining compatible with the format of possible future sources of input data.

The grid mesh system is rectangular to a polar stereographic projection of the northern hemisphere. The spacing between successive grid points at middle latitudes is about -1 nautical miles. The J-axis is parallel to the great circle defined by 100 degrees east longitude and 80 degrees west longitude. The north pole is at ($I = 32\theta 1$, $J = 32\theta 1$). The equations relating latitude (Lat) and longitude (Lon) to I and J are:

$$I = 32\theta 1 + R \cos A$$

$$J = 32\theta 1 + R \sin A$$

where

$$R = 3120.4375 \tan ((90^\circ - \text{Lat})/2)$$

$$A = 10 - \text{Lon}$$

and longitude is defined as positive in the eastern hemisphere and negative in the western.

3.5 Importance of the Geocoded Grid System Concept

Throughout the description of the Hydrology Scenario, reference was made to the geocoded data management system. During the design phases of the Hydrology Scenario it was decided that the World Meteorological Organization (WMO) grid was to be used as the standard frame of reference. Advantages of using the WMO grid include:

1. Uniquely defined globally.
2. Easily related to latitude and longitude.
3. Regularly spaced and shaped grid cells.
4. Size of unit cell easily adaptable to users needs.
5. Cells easily specified by a triple index (I,J,K).
6. Telescoping resolution for varying input data.

It is extremely important to point out the central role which this type of geocoded grid system plays in the entire design. Any type of information management system using geocoded information must establish some type of geocoded frame of reference. In a true geocoded information management system, the frame of reference provides the frame work for storing and retrieving all of the geocoded information. In the Hydrology Scenario the grid system provides the basic indices used to reference all of the data. The ultimate flexibility and utility of the Hydrology Scenario is closely tied to the capability to reference a large variety of data types through a single grid system.

4.0 HYDROLOGY SCENARIO DOCUMENTATION

This section describes the physical structure of the hydrology data base and its environment and in conjunction with the software documentation in Appendix A provides a user's manual for both system generation and hydrology applications. The discussion of file structures is by necessity directed toward persons with a background in data processing. System generation is also an area which is best left to a computer professional; however, system generation documentation has been provided such that it could be accomplished by a person with a user oriented background.

4.1 System Generation Documentation

4.1.1 System Environment

The hydrology data management system was designed to operate on a PDP 11/70 or 11/45 under the RSX-11-D operating system with a minimum of 64K main memory. Mass storage requirements will vary with each application, but for most purposes a single RP04P 88 megabyte disc pack will provide adequate storage for software and data files. All data files must reside on the same volume in order to be processed by the system software. Source, object, and task modules may reside on a separate volume if necessary.

All source modules are written in FORTRAN for compilation on PDP's FORTRAN IV-PLUS compiler. Object modules may be interchangeable among PDP 11's operating under the same system but recompilation is recommended. Task modules should never be transferred between systems. As the data management

system has neither an executive of its own nor any interdependent tasks, there is no need for any shareable global areas.

Under normal circumstances, there is no need for the user to operate under a privileged UIC.

4.1.2 File Structure

The hydrology data base consists of four files, a label and an index file for overhead functions, and an archive and a daily file for actual data storage. Overhead type files have a fixed format whereas the data files may be varied with each application.

The label file is transparent to the user but contains information necessary for processing the other three files. The file is named NAME.LBL, where NAME represents a one-to nine-character data base name which conforms to the standards of PDP's file control services. The label file contains three records; one each for the index, archive, and daily files, and is accessed sequentially. The format of a label record is outlined in Table 4-1. The index file defines a rectangular area indexed by I,J coordinates which contain the entire watershed. This random access file contains one 8-byte record for each I,J cell within the rectangle. The file is sorted first by J coordinate then by I coordinate, both in ascending order. Additionally, the file contains one header record which defines the limits of the rectangle. Both index record formats are outlined in Table 4-2. The index record for a given I,J can be located using the following equation:

LABEL RECORD

| <u>BYTE POSITIONS</u> | <u>CONTENTS</u> | <u>FORMAT</u> |
|-----------------------|-------------------|---------------|
| 0-3 | NUMBER OF RECORDS | BINARY |
| 4-5 | RECORD LENGTH | BINARY |
| 6-23 | FILE NAME | ASCII |

TABLE 4-1

INDEX RECORDS

HEADER RECORD

| <u>BYTE POSITIONS</u> | <u>CONTENT</u> | <u>FORMAT</u> |
|-----------------------|--------------------|---------------|
| 0-1 | MINIMUM I VALUE | BINARY |
| 2-3 | NUMBER OF I VALUES | BINARY |
| 4-5 | MINIMUM J VALUE | BINARY |
| 6-7 | NUMBER OF J VALUES | BINARY |

POINTER RECORD

| <u>BYTE POSITIONS</u> | <u>CONTENT</u> | <u>FORMAT</u> |
|-----------------------|---|---------------|
| 0 | BASIN NUMBER - K=1 | BINARY |
| 1 | BASIN NUMBER - K=2 | BINARY |
| 2 | BASIN NUMBER - K=3 | BINARY |
| 3 | BASIN NUMBER - K=4 | BINARY |
| 4-7 | POSITION OF DATA RECORD FOR K=1 IN ARCHIVE OR DAILY FILES | BINARY |

TABLE 4-2

$$\text{REC}_{\text{number}} = (\text{J}-\text{J}_{\text{min}}) \times \text{NUMI} + (\text{I}-\text{IMIN}) + 2 \quad [4-1]$$

The index file name is constructed by appending a type qualifier of IDX to the data base name.

The archive file is one of the two direct access data files in the data base and is used to store data which remains constant with time. It contains four records for each index record which indicates a populated I,J cell. The archive length may be varied at creation but must be greater than 14 bytes. An 80-byte length provides compatibility with the RSX text editor. The first record in the archive file is a header recorder which is not used. It is included only to provide conformity with the daily file format. The format of the archive data record is described in Table 4-3. Each archive record contains an offset pointer which when added to the current record number indicates the record number of the next populated K cell within the same basin. The archive file name is constructed by appending a type qualifier of ARC to the data base name.

The daily file is the second random access data file and data base, and is used to store temporal information. The organization is identical to that of several concatenated archive files; one for each date. Each date contains the same number of records as the archive file. In addition to the data records the daily file contains one header record which is described in Table 4-4. To locate the data record for a given I,J of a given date, the following equation is used:

ARCHIVE DATA RECORD

| <u>BYTE POSITIONS</u> | <u>CONTENTS</u> | <u>FORMAT</u> |
|-----------------------|--|---------------|
| 0-3 | I COORDINATE | ASCII |
| 4-7 | J COORDINATE | ASCII |
| 8-9 | K CELL NUMBER | ASCII |
| 10-11 | BASIN NUMBER | ASCII |
| 12-13 | POINTER TO NEXT RECORD WITHIN BASIN | BINARY |
| 14-17 | GROUND COVER - WATER | ASCII |
| 18-21 | GROUND COVER - MARSH | ASCII |
| 22-25 | GROUND COVER - FOREST | ASCII |
| 26-29 | GROUND COVER - VEGETATION | ASCII |

TABLE 4-3

DAILY RECORDS

HEADER RECORD

| <u>BYTE POSITIONS</u> | <u>CONTENT</u> | <u>FORMAT</u> |
|-----------------------|-------------------------------|---------------|
| 0-3 | NUMBER OF RECORDS PER DATE | BINARY |
| 4-5 | NUMBER OF DATES | BINARY |
| 6-7 | POSITION OF LAST DATE ENTERED | BINARY |
| 8-9 | DATE #1 (DDD) | BINARY |
| . | . | . |
| . | . | . |
| . | . | . |
| . | . | . |
| 68-69 | DATE #31 (DDD) | BINARY |

DATA RECORD

| <u>BYTE POSITIONS</u> | <u>CONTENT</u> | <u>FORMAT</u> |
|-----------------------|--|---------------|
| 0-3 | I COORDINATE | ASCII |
| 4-7 | J COORDINATE | ASCII |
| 8-9 | K CELL NUMBER | ASCII |
| 10-11 | BASIN NUMBER | ASCII |
| 12-13 | POINTER TO NEXT RECORD WITHIN BASIN | BINARY |
| 14-19 | JULIAN DATE (YYDDD) | ASCII |
| 20-25 | PRECIPITATION | ASCII |

TABLE 4-4

$$\text{REC}_{\text{number}} = (\text{IREC}) + (\text{NDATE}-1) \times \text{NRECPD} \quad [4-2]$$

where IREC is the record number obtained from the index file, NDATE is the position of the date in the daily file, and NRECPD is the total number of records for each date in the daily file. The pointer to the next record within the basin is identical to its archive file counterpart. The daily file name is constructed by appending a type qualifier of DLY to the data base name.

4.1.2 System Generation

This discussion of the data base generation procedure assumes all data management software has been successfully compiled and task built, and that a properly initialized RP04P disk pack has been mounted on an RD: device. Complete documentation for all software modules referred to in this section can be found in Appendix A.

The only pre-processing function required before file generation is the definition of the watershed boundaries and the boundaries of each sub-basin. These are defined by the maximum and minimum I and J coordinates contained within the watershed and by the latitude and longitude of each vertex of the sub-basin polygons.

Once the watershed boundaries are defined the index file may be created by executing the program CINDEX. This requires the maximum and minimum I,J and the data base name as inputs. After completion there should exist an index file which contains a header record describing the file structure

and the correct number of dummy index records. CINDEX also creates the label file and the index file label.

The next task is to fill in the basin keys of the index file. This is accomplished by running the program POLYB. This requires the latitude and longitude coordinates of each vertex for each sub-basin in the watershed. POLYB converts these coordinates to IJK's, constructs the sub-basin polygon, and inserts the corresponding basin keys for each K-cell within the sub-basin. After completion the index file completely describes the structure of the watershed.

The creation of the data files may now be accomplished by running the program CDATA. This program will create either the archive or the daily file or both simultaneously. The only inputs required are the record lengths for each file and the number of dates desired in the daily file. All other information is extracted from the completed index file. The completed files will contain data records with IJK and the basin numbers filled in. The daily file will contain a completed header record. Label entries will also be created for each file.

At this point it is advisable to run the program DISPLAY to produce an image map of the basin keys. This map can be compared with the known watershed structure to verify the structure contained in the index, archive, and daily files.

The final step in the file creation procedure is to run the program NBASIN which will traverse the archive and daily files and insert the pointers which indicate the position of the next data record within the same basin. These pointers are useful in aggregation of data from the cell level to the basin level. After completion of NBASIN, the data base is ready for data insertion.

4.2 Users Guide Documentation

This section covers the handling of remotely sensed data for insertion into the data base and the retrieval of that data in image format. The handling of SMS imagery requires pre-processing by the METPAK system to select the desired window and obtain registration information. LANDSAT classification data must be generated using the Image 100 System as supplied by General Electric. The flow of data through the data management system is outlined in Figure 4.1.

4.2.1 Methods of Data Insertion

Two options are presently available for insertion of data into the data base. These options are:

1. Derived precipitation estimates from SMS.
2. Ground cover classification from LANDSAT.

More important is the fact that these options provide the basic capacity for handling remotely sensed data at various levels of resolution. This basic capability provides a foundation which may be readily expanded upon to provide large scale processing capability.

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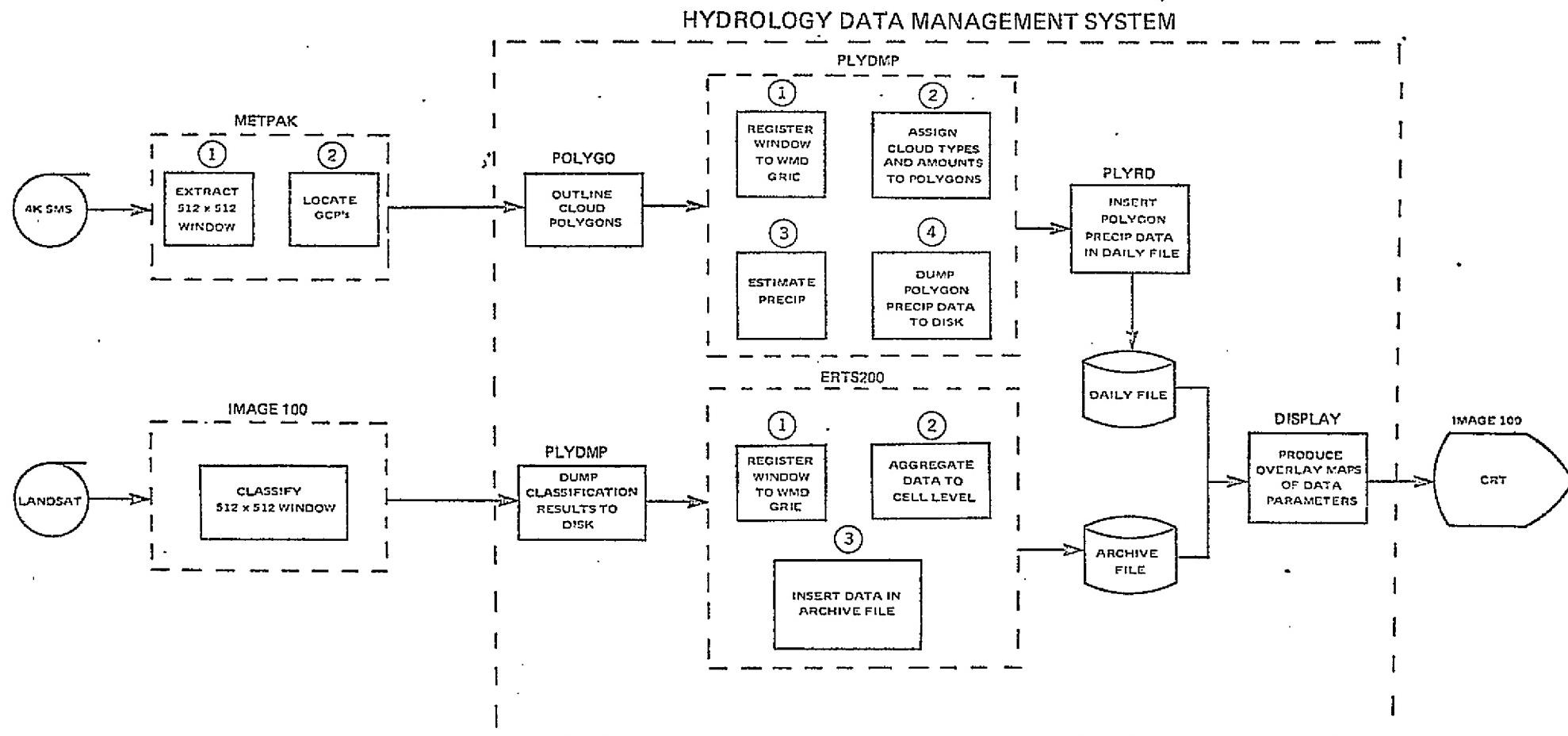


FIGURE 4.1 DATA FLOW THROUGH THE AOIPS HYDROLOGY DATA MANAGEMENT SYSTEM

4.2.1.1 Precipitation Data

The derivation of precipitation estimates requires that the user have an SMS image, windowed and registered by METPAK, on the screen of the Image 100. The first step is to run the program POLYGO (Section A-3.8) outlining all cloud polygons of those cloud types which produce precipitation. Once this is accomplished the polygon information can be processed by the program PLYDMP (Section A-4.6). When option one is selected the user will be prompted for cloud type information from which precipitation estimates are derived. This information is dumped to a disk file for insertion into the data base by the program PLYRD (Section A-4.7).

PLYRD requires the image registration information obtained from METPAK. Once the image has been registered to the WMO grid, processing simply involves the insertion of the previously defined precipitation estimates into the data base daily file at the I,J cell level.

4.2.1.2 LANDSAT Classification Data

Derivation of ground cover estimates requires that a LANDSAT image of the watershed area has been previously classified by the Image 100 system, and the results are stored on the theme planes of the Image 100.

The first step is to convert the theme data into a form which can be accepted by the program ERTS200 (Section A-4.9). This is accomplished by running the

program PLYDMP, specifying option number two. This will create a disk file of the theme information.

Next ERTS200 may be run to register the image and process the classification data. The REGISTER option must be specified first to register the image to the WMO grid. After registration is completed the INSERT option may be selected to aggregate the data to the K-cell level and insert it into the data base archive file.

4.2.2 Methods of Data Retrieval

The capability to display any parameter in both the archive and daily files is provided by the program DISPLAY (Section A-4.8). The user specifies the file to be displayed (archive or daily), the parameter to be displayed, and the maximum and minimum parameter limits. The output is in the form of a binary map with all cells in which the data parameter falls within the specified limits turned on and all other cells turned off.

This provides the hydrologists with the ability to obtain an instant overview of any data base parameter. It is especially useful in the delineation of areas subjected to extreme conditions (i.e., drought or heavy rainfall). Also, by overlaying several of these maps, a graphic display of the correlation between data parameters may be achieved.

5.0 AOIPS HYDROLOGY DEMONSTRATION

The emphasis throughout this Contract was directed toward developing a demonstration of the AOIPS Water Resources Data Management System. As partial fulfillment of the Contract deliverable, Earth Satellite Corporation performed a demonstration of the Water Resources Data Management System on August 25, 1976. A booklet was prepared for use in that demonstration to provide a synopsis of the work being performed and to show selected examples of the products being demonstrated. Chapter 5 is a reproduction of the material contained in the booklet.

5.1 INTRODUCTION

Earth Satellite Corporation, working under NASA Goddard Space Flight Center Contract No. NAS5-22894, has designed a geocoded data management system applicable for hydrological analysis. The central features accommodated by the system design include:

1. Ability to process a variety of data types related to hydrological parameters;
2. Ability to store and retrieve data within a common framework for all data types;
3. Ability to analyze spatial and temporal relationships between hydrologically related parameters through video displays and overlays;
4. Ability to drive existing main-frame hydrologic models from outputs of the system.

The emphasis throughout the contract was to demonstrate the utility of the Atmospheric and Oceanographic Information Processing System (AOIPS) for hydrological applications. Within that context, the geocoded hydrology data management system was designed to take advantage of the interactive capability of AOIPS hardware. Portions of the system which best demonstrate the interactive nature of the hydrology data management system were implemented on the AOIPS. A hydrological case study was prepared using all data supplied by GSFC for the Bear River watershed located in northwest Utah, southeast Idaho, and western Wyoming.

5.2 HYDROLOGY APPLICATIONS ON AOIPS

The river forecast problem posed itself as an ideal hydrological application for AOIPS. The problem addresses questions of information needs for urban flood forecasting and seasonal water run-off forecasting which in turn are used for public disaster warnings, hydroelectric power management, and irrigation management. Additionally, the problem contains many elements which could best be served by remote sensing and interactive computer processing. Finally it is noted that components of the river forecast problem are of joint interest to other application scientists. Meteorology, agronomy, and rangeland management have interests in precipitation estimates, and soil moisture budgeting, as well as the calculation of potential evapotranspiration.

The design of the system to demonstrate the hydrology application on AOIPS was constructed within the context of existing models and currently available data sources. An effort was made to design the system to supply the needs of the most complex models currently in use. It would be hoped that this design concept would accommodate most new input elements required by future models, and certainly should supply all of the needed elements of less complex existing models.

5.2.1 Existing Hydrology Models

The purpose of hydrology models is to assess the effect of a rain or other event on the water flow rate within a watershed basin. The model itself is a mathematical abstraction and provides the researcher with the ability to examine the consequences of decisions such as channel modification or to predict the effects of snowmelt. In either case, the variations in stream flow can be estimated and these data used to make policy decisions.

Each of the three models discussed in this section has two basic components:

1. Estimation of stream or system inflow with each sub-basin of the watershed;
2. Combination of these inputs to predict unit hydrographic readings at selected points within the stream system.

Each of the models estimates mean precipitation over the basin area from weighted ground station data. These data are combined to estimate the area mean precipitation for the current time interval or event. Combined with parameters describing the ground condition of the basin (e.g. current soil moisture content, soil type, land use, slope of terrain, etc.), it is possible to estimate the amount of ground run-off entering the stream system from that sub-basin. The stream or river system is a mathematical network, each component of which possesses certain characteristics, such as storage, through-put time, elevation, etc. Inflow from each sub-basin is entered into the network at that time interval. A certain amount of that component's inflow will "pass-through" and enter the next downstream element. This process is repeated for each interval over all network elements and the aggregate effects measured at hydrographs placed at various locations within the stream network. These hydrographic data can then be analyzed to measure the effects of decisions or events.

5.2.2 Hydrology Model Data Requirements

Each of the currently existing hydrology models has certain basic data requirements necessary to run them. In each case historic stream flows or station precipitation data are combined with

static regional data to optimize specific coefficients for the model. Variables including land use, soils, impervious area, vegetation cover are used to estimate parameters such as infiltration indices, basin time lags, etc. The historic data are input and the model iteratively run until the prediction closest to observed data is obtained.

Operationally it is necessary to initialize the model with the status of the stream system. Parameters such as current stream flow rate at each hydrograph can be used. Similarly for those models with a snow melt component an estimate must be made of the snow pack status. Meteorological parameters are required several times a day to provide accurate estimate of the environmental factors. Specifically, precipitation estimates, temperature, wind, and radiation measurements are used to estimate evapotranspiration potential, mean precipitation, etc. These data are in turn used to modify the hydrologic status of the basin system within the framework of the models discussed above.

5.2.3 Data Requirements Satisfied By Remotely Sensed Data

Many of the data requirements for the existing hydrologic models can be supplied through the uses of remotely sensed data. Land use, soils, and vegetation information can be obtained using high resolution imagery. Additionally, sufficiently detailed land use data can be used to supply ground and vegetation cover information. From these data, initial estimates of infiltration indices and other soils surface parameters can be inferred.

Probably the greatest contributions of remote sensing are in the areas of precipitation estimation and area monitoring. As currently implemented by existing hydrology, each model estimates area precipitation based on observations at selected stations in the basin area. Estimates of point precipitation are made by a weighted sum of surrounding station observations. The weights used are proportional to the distance between the point in the observing station. Given a relatively dense network of reporting stations this approach works reasonably well; however, in relatively inaccessible regions or in areas where the network is sparse, the accuracy of this technique is poor. One solution which can be used is to estimate the location and amount of precipitation from meteorological satellite data such as SMS visible and infrared imagery. This data obtained repetitively during the day can be analyzed as to cloud type and brightness. These descriptors are then used to empirically estimate precipitation from that cloud mass.

Similarly it is possible to use satellite imagery to monitor the snow pack. Area measurements of snow cover can be combined with topological data to estimate total water equivalent. As snow melt begins satellite data can be used to monitor the melt process. These observations can be used to refine the operational model estimates and use in flood prediction models.

5.3 HYDROLOGY SCENARIO

5.3.1 System Overview

Earth Satellite Corporation hydrologists began by preparing an AOIPS hydrology scenario. Within this work, all the currently existing major hydrology models were studied with particular regard to input data requirements. Emphasis was placed on identifying those hydrology parameters which are currently available (or possibly available in the future) from remotely sensed data. The hydrology applications data processing system was designed with the intent of being capable of processing all of the input data requirements needed by the most sophisticated hydrology models in existence today. This set of design allows all less sophisticated hydrology model data requirements to be provided as a subset of a complete system.

Two immediate questions have to be resolved concerning the system design. First, since the system required storing geocoded information a particular grid system had to be adopted. Second, since input data at a variety of scales and projections would have to be processed, a "standard resolution element" had to be established; staff hydrologists agreed that the World Meteorological Organization (WMO) grid system provided an excellent grid framework for storing the geocoded information. The WMO grid is well defined for all parts of the globe and is easily adapted to different size resolution elements.

The standard cell resolution element was defined to be one square mile. The one square mile cell was agreed upon because it provided a good compromise between the national resolution sizes of the various types of input data. The problem existed, however,

that the smallest resolution unit accepted by any of the hydrology models was the sub-basin unit. Depending upon application, a sub-basin may be as small as a single stream basin or as large as an entire river basin. The concept of dual data files at different resolution emerged as the natural resolution of this problem. The first data file stored at the one square mile cell resolution served as an intermediate step between the natural resolution of the input data and the final required resolution of the sub-basin level. In this case, a sub-basin is defined as a specific aggregation of any number of one mile cells. At this point, the fundamental design features of the information processing system had been defined:

1. All initial processing of input data would be performed at whatever unit resolution was most logical for that particular data type;
2. Initially processed data would be converted and stored at the intermediate one square mile cell level. This may require aggregating data in the case of LANDSAT/ MSS-derived inputs, or spatial interpolation of data as in the case of point weather station data;
3. The one square mile cell data would be aggregated upward to the sub-basin level with the sub-basin being defined by the application user.

In addition to considering the spatial properties of data storage, it was necessary to also consider the temporal properties of the data to be processed. As noted in the AOIPS hydrology scenario paper it is necessary to provide the hydrological models

with slowly varying data such as soil type, land use cover, and porosity maps as well as the rapidly varying data such as maximum and minimum temperatures and precipitation. Since it would be inefficient to maintain all of the slowly varying data within the same data file as the rapidly varying data, it was decided to maintain two types of data files:

1. An archive file with all of the slowly varying data.
2. A daily file with only information related to a specific observation date.

In total, there would be four separate data files maintained on the hydrology data management system on AOIPS:

1. Cell Archive - containing only slowly varying information entered at the one square mile cell level.
2. Cell Daily - containing only daily inputs entered at the one square mile cell level.
3. Basin Archive - containing all slowly varying information aggregated up to the basin level from the sub-level.
4. Basin Daily - containing all daily inputs aggregated up to the basin level from the cell level.

In reality, the only difference between the archive data files and the daily data files is in the meaning associated with the numbers stored in the data files and the frequency with which the files are updated with new information. The same file structure is used for both sets of files. Figure 1 shows an overview of the hydrology scenario design.

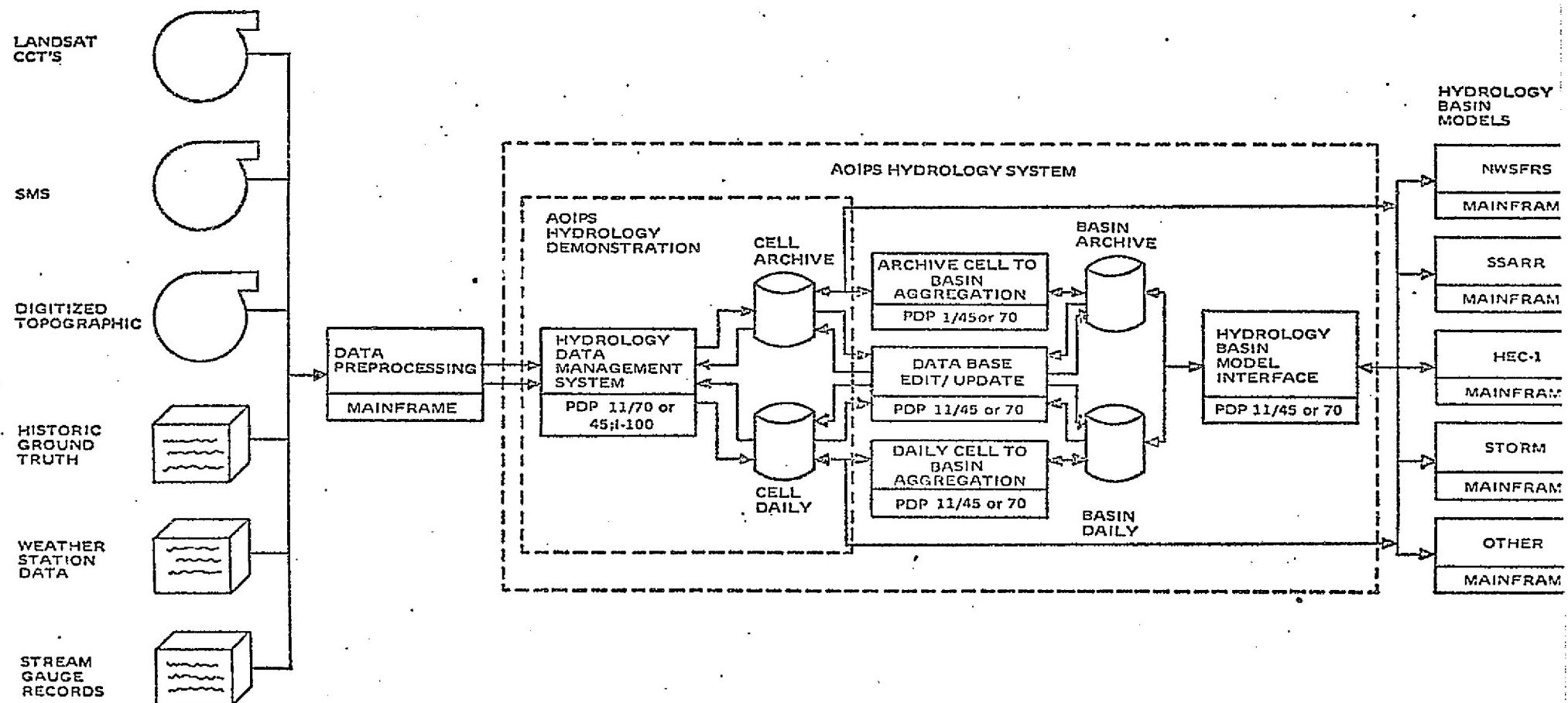


FIGURE 5-1: HYDROLOGY SCENARIO DESIGN

5.3.2 System Capabilities

Several important features of this design should be noted:

1. New types of information may be easily accommodated with a minimum amount of new programming.
2. Users have an opportunity to study the impact of hydrological events at four different levels: original input data resolution, one-mile cell resolution, basin resolution, and finally at the hydrology model "resolution."
3. New models may be tested by entering "pseudo" data at any appropriate point in the system.
4. The hydrology basin model interface allows the user to easily compare the results of different hydrology basin models.

As mentioned earlier the implementation of the AOIPS hydrology system for the demonstration was directed towards portions of the Hydrology Data Management System. The ability to process SMS data, LANDSAT data, and topographic data was developed to demonstrate those features of the system. Additionally, the ability to generate the cell level data files as well as to enter, retrieve, display, and overlay information from those files was developed for the demonstration. The ability to process other data types including meteorological weather station data, historical ground truth data, stream gauge records and other point source data have not yet been developed.

5.3.3 AOIPS Capability as Applied to the Needs of the Hydrology Application

In the initial phases of the contract work, the usefulness of AOIPS to the hydrology application science appeared to be prin-

cipally as a system to process raw data into a form acceptable for use by existing hydrology models. For example, the AOIPS system could be used to transfer SMS data from its raw form (digital imagery) to a form accepted by NWSRFS (mean basin precipitation). As EarthSat scientists gained experience in using AOIPS hardware, it became apparent that this important function may not ultimately be the principal use of AOIPS by hydrologists. The interactive capability to display, overlay, and in general analyze digital data, tied directly to a geocoded data base which contained all hydrologically-related parameters promises to be an extremely powerful tool for the research hydrologist to use in improving existing models and in developing new models. This marriage of display capabilities with geocoded information data files containing a variety of data types provides the researcher with the capability to easily investigate spatial and temporal relationships between observed phenomena. The interactive nature of the system will allow the user to query the information files for specific types of events, "track" the events as they are processed by the AOIPS system, and then eventually by the large river forecast hydrology models. This type of application user "hands-on" experience should result in valuable improvements in the understanding of hydrology-related phenomena.

5.4 AOIPS HYDROLOGY SOFTWARE DEMONSTRATION

This section of the AOIPS Hydrology Demonstration is meant to compliment the actual demonstration performed on the AOIPS System. The figures shown here are selected from the actual displays to be generated on the screen of the Image 100. With the single exception of the multispectral classification figure all of the figures were generated on the DICOMED recorder. The multispectral classification results figure was taken with a 35 mm camera.

The Hydrology Data Management System will be demonstrated using all "real" data obtained for the Bear River Basin. The Bear River Basin, located in northeast Utah, southeast Idaho and western Wyoming was selected because it is a relatively small closed hydrological system. Figure 5-2 shows the extent of the basin and the division into three sub-basin areas. There are 56 stream gauging stations located within the River Basin.

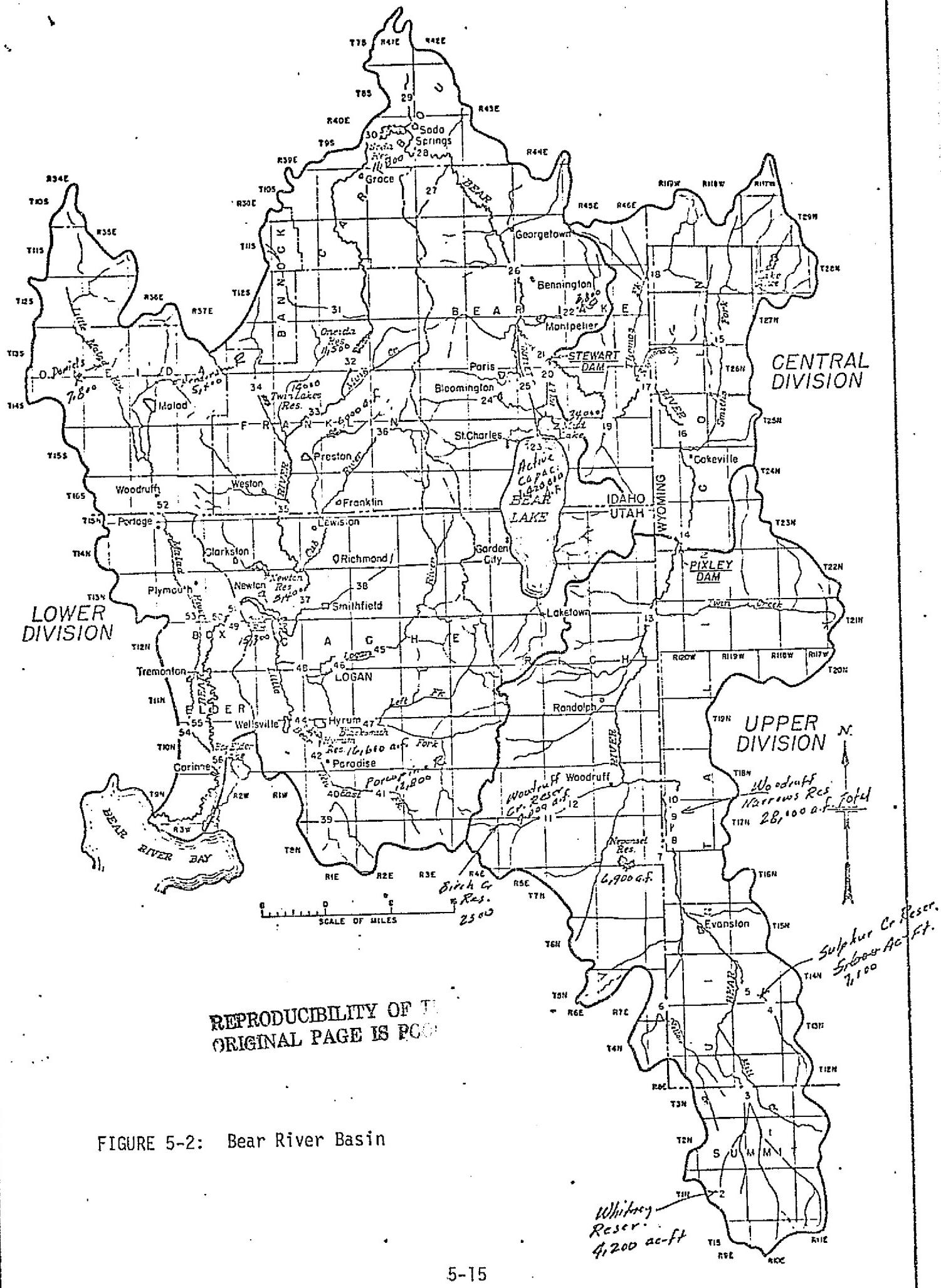


FIGURE 5-2: Bear River Basin

Figure 5-3 is a full frame LANDSAT synoptic view of the Bear River Basin. The terrain in the watershed is very rugged with mountain peaks as high as 9500 feet. The large body of water located in the southwest corner of the image is the Great Salt Lake.

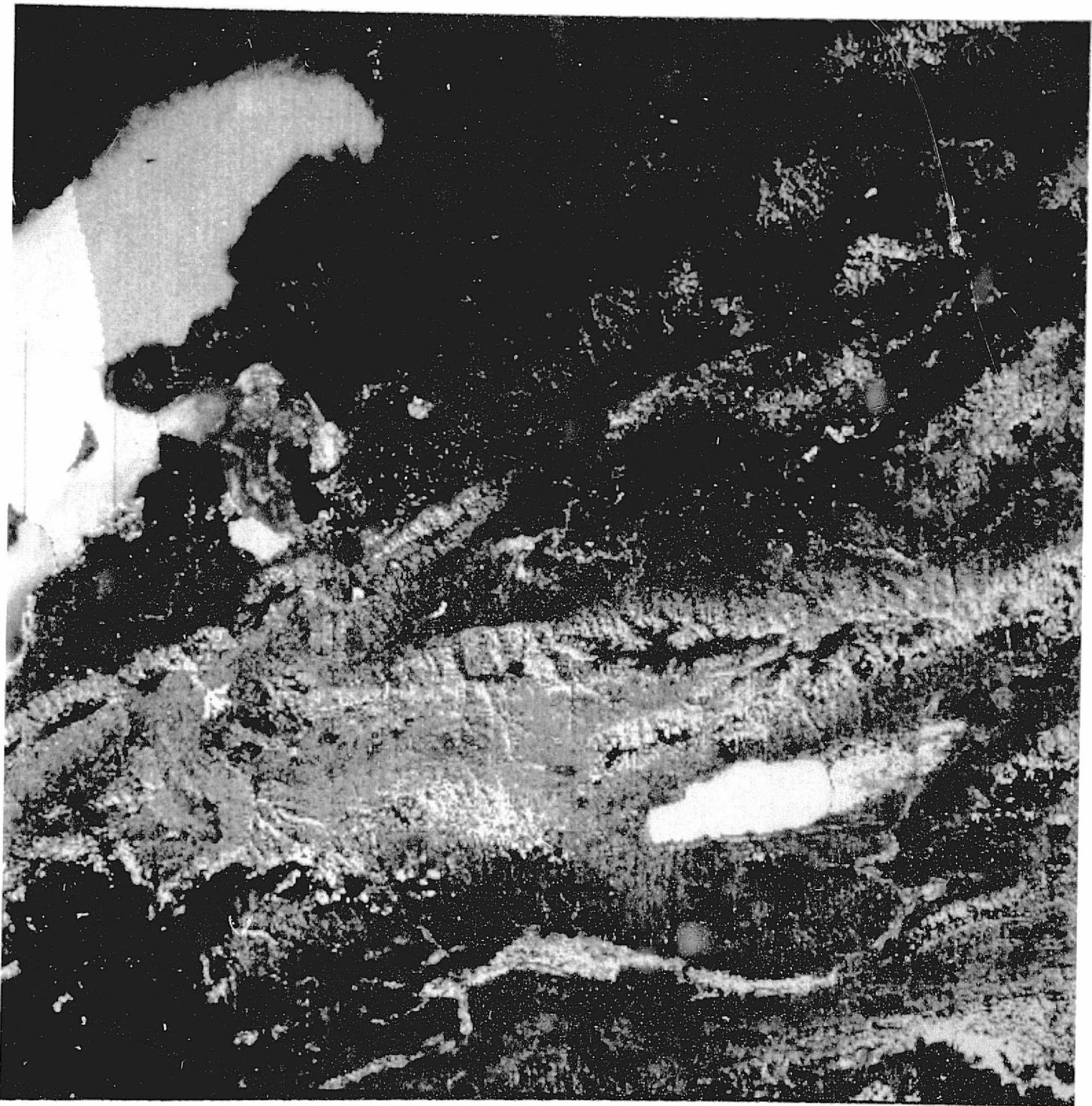


Figure 5-3 Full Frame LANDSAT of Bear River Basin

The first task in generating the Bear River Basin hydrology data bases was to digitize the three sub-basins within the watershed. The Bear River Basin map shown in Figure 5-2 was used to manually "polygonize" the sub-basins. The vertices of the sub-basin polygons were converted to latitude and longitude and input to the Hydrology Data Management Software. The Hydrology Data Management Software constructed the skeleton structure of the data bases from the polygon data. Each I,J,K, cell within the river basin was assigned to its appropriate sub-basin. Figure 5-4 shows a display taken from the data base which shows the assignment of cells to sub-basins.



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Figure 5-4 Bear River Watershed Sub-basins

After the initial data files have been generated, remotely sensed data may begin to be processed and entered into the data bases. Figure 5-5 shows an example of LANDSAT imagery covering the Bear Lake region. The LANDSAT data shown in this figure has been aggregated up to an effective 200 meter pixel resolution.



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Figure 5-5 LANSAT 200 Meter Sampled Image Around Bear Lake

The LANDSAT data shown in Figure 5-5 was multispectrally classified using the General Electric Image 100. The results of this classification are shown in Figure 6. Training sets were identified for 4 classes of data:

- 1) water
- 2) marsh
- 3) forest
- 4) natural vegetation

The results of the multispectral classification were aggregated up to the 1 square mile cell level. The percentage of each cell assigned to each of the four classes was entered into the Archive Cell Data Base.



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Figure 5-6 LANDSAT Multispectral Classification Results

In addition to processing LANDSAT data, the Hydrology Data Management System allows for the use of SMS data to provide precipitation estimates. Figures 5-7 and 5-8 show two typical SMS images over the Bear Lake area. Using the Image 100 cursor to outline cloud polygons the user may identify cloud extent, type and amount. The user is prompted to enter the cloud type and amount for each polygon. The system then estimates precipitation produced by those clouds. The precipitation estimates are then entered into the daily all data base.

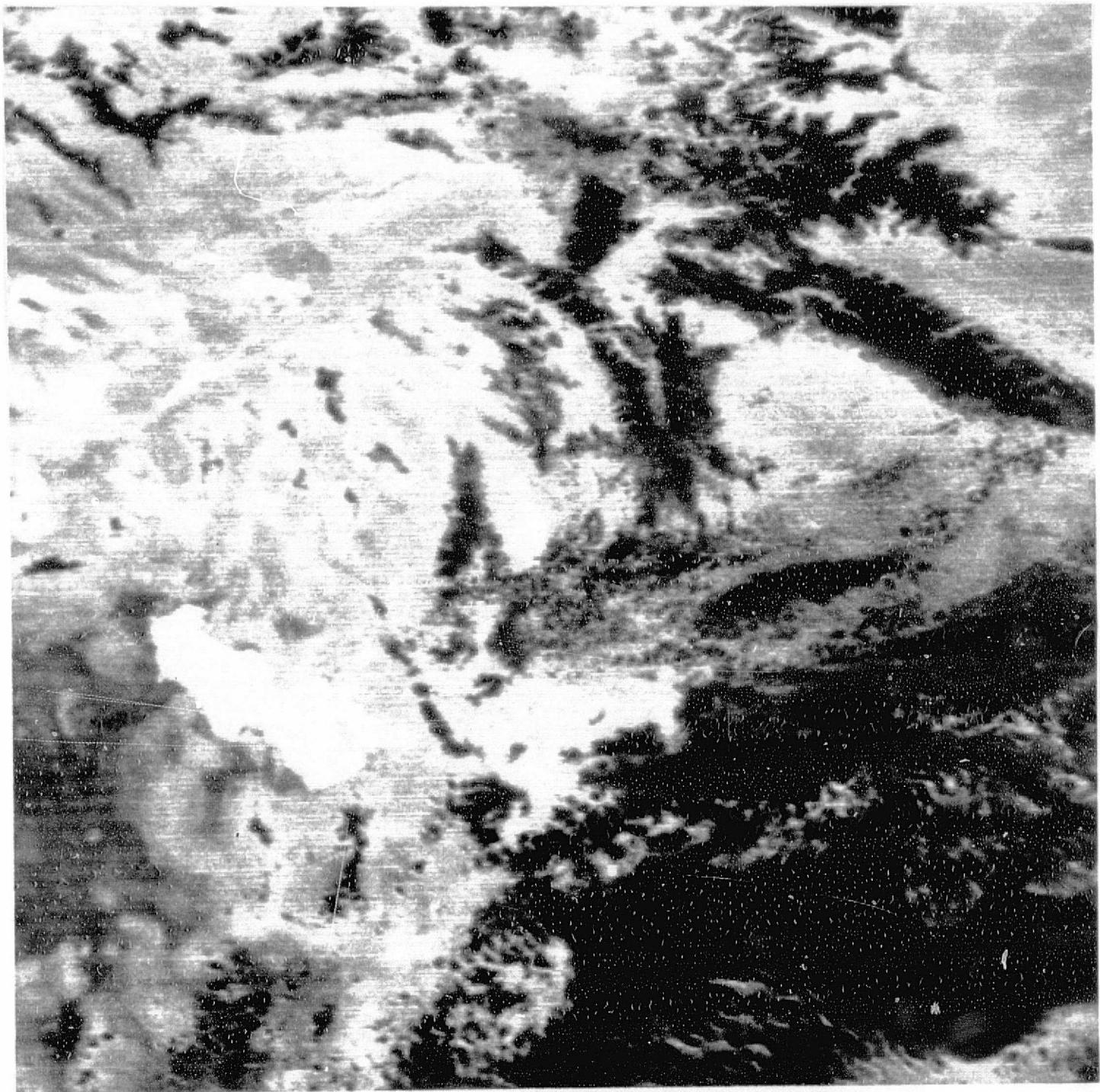


Figure 5-7 SMS Image Over Bear Lake

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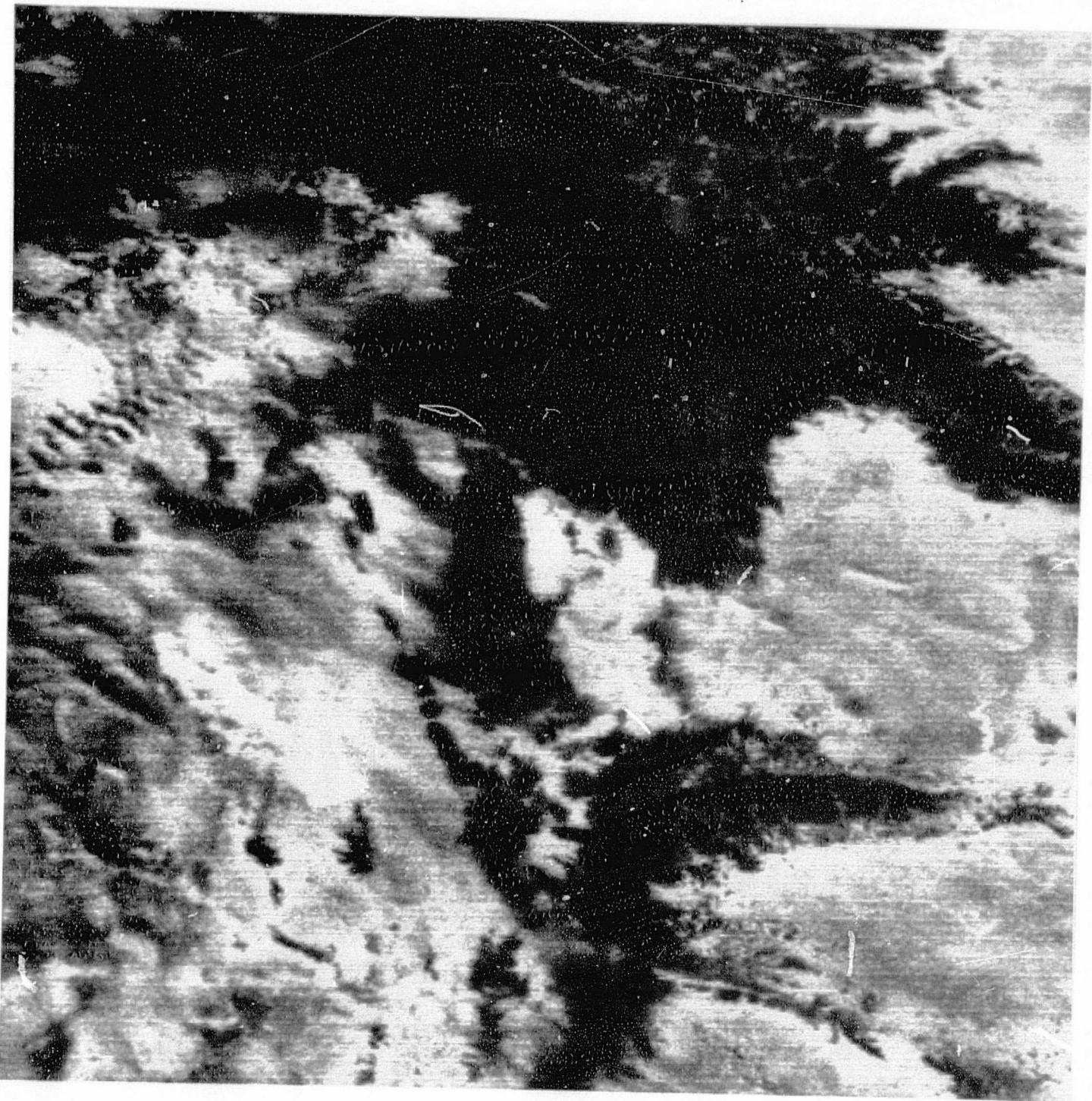
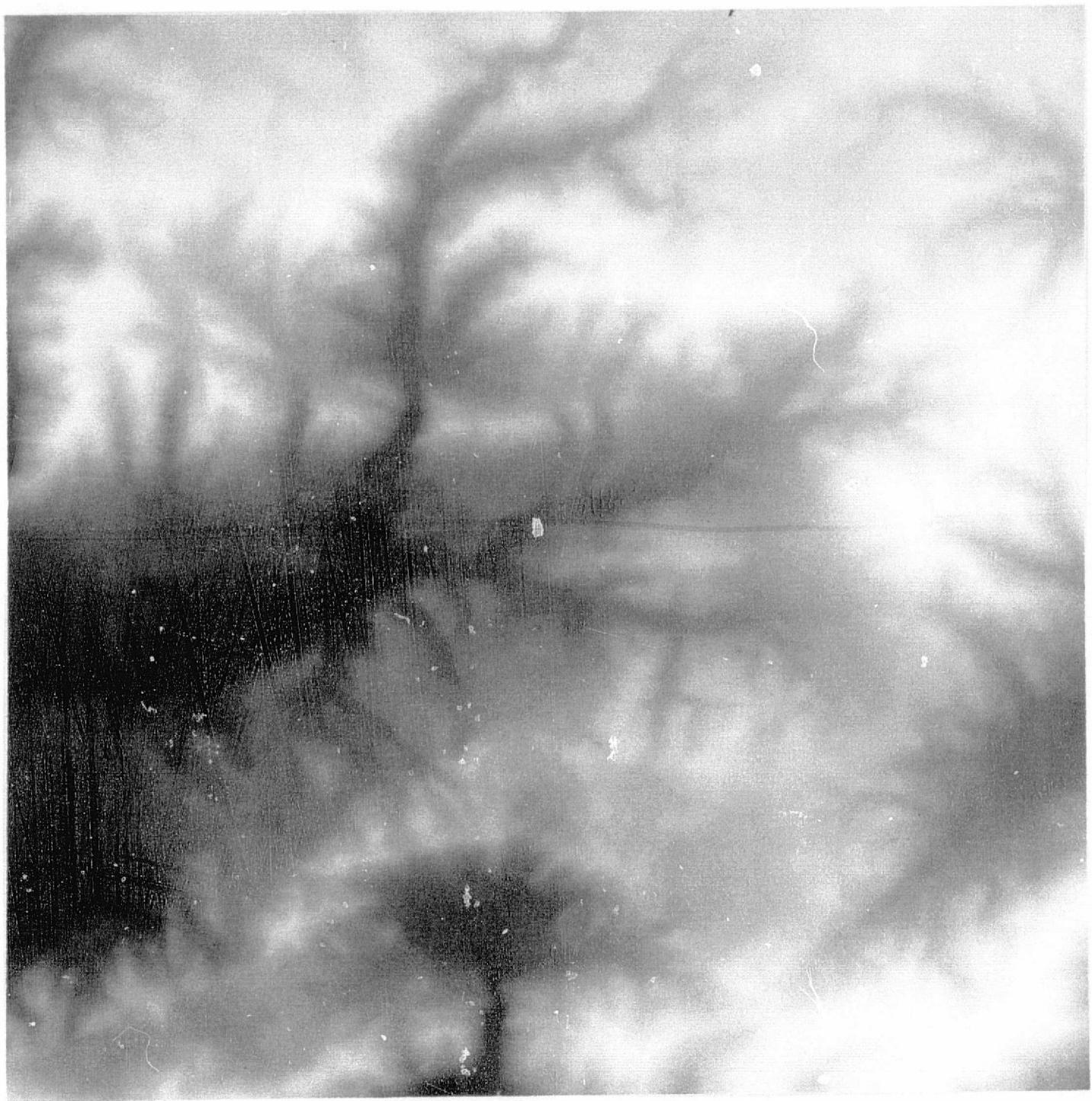


Figure 5-8 SMS Image Over Bear Lake

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The final type of data processing to be shown at this demonstration is digitized topographic data. Figure 5-9 shows an example of raw topographic data. The gray map display was generated by stretching the topographic elevation range of 0 to 10,000 feet over a gray value interval of 0 to 255. Each step in gray value represents a rise of approximately 39 feet in elevation. The lighter the gray shade on Figure 9, the higher the elevation. This topographic data may be entered into the Archive Cell Data Base in the same way that the LANDSAT data was entered.



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Figure 5-9 Raw Image Display of Topographic Data

The final display shown in Figure 5-10 is a 3 dimensional perspective plot generated from the digitized topographic data. This type of plot can be interactively produced for any area for which topographic data is available. The 3 dimensional perspective plot allows the user to easily visualize the topography of the area to be analyzed.

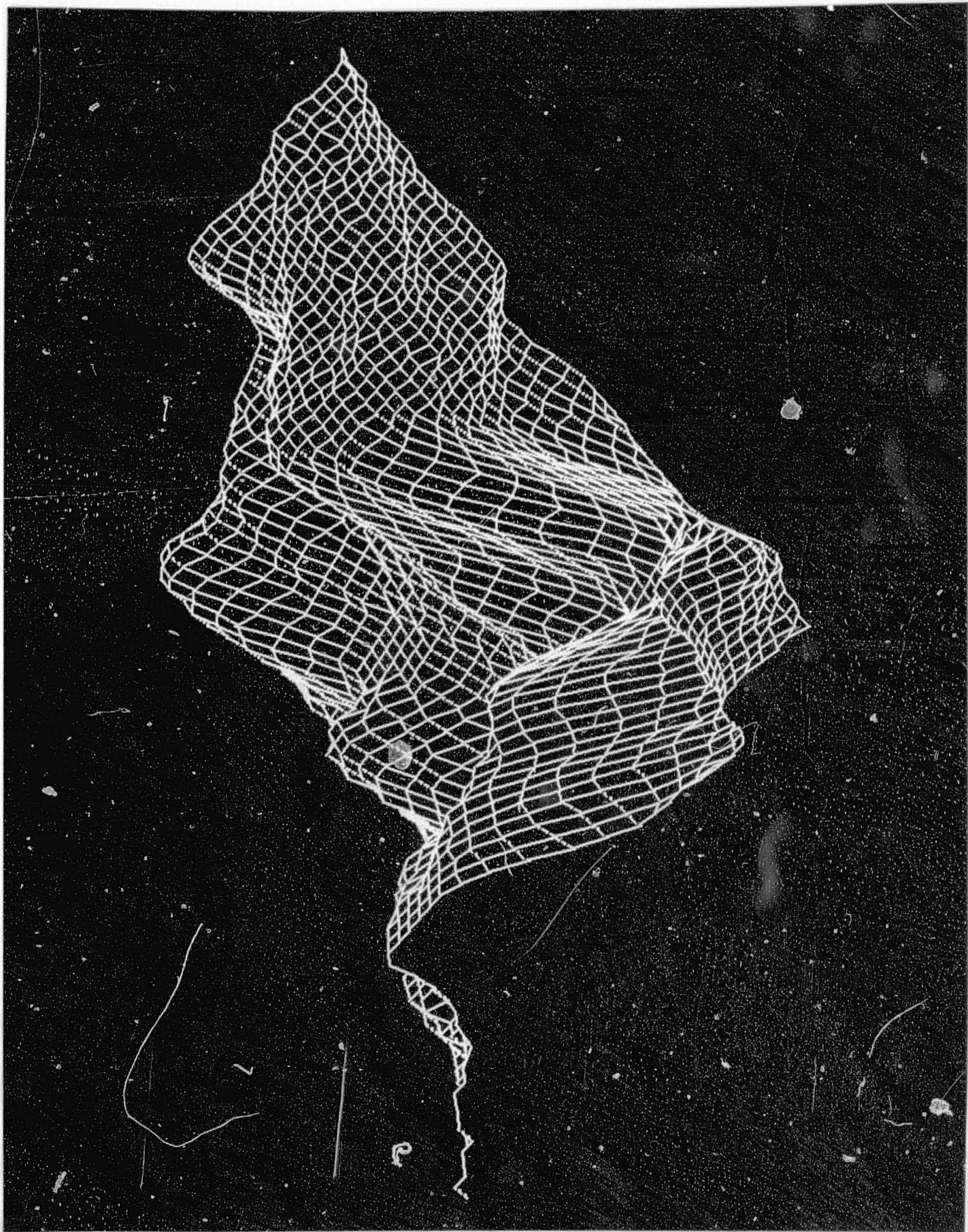


Figure 5-10 Perspective Plot Generated from Topographic Data

5.5 CONCLUSIONS AND RECOMMENDATIONS

5.5.1 Conclusions

Previous experience by EarthSat personnel in a variety of application areas has demonstrated the utility of storing implementations data in a geocoded reference system. Work performed under this contract has shown the increased advantages of directly tying the geocoded data base to an interactive display capability such as that available on AOIPS.

In specific applications of hydrology it should be pointed out that the existing hydrology models consider as their "smallest unit of information" the watershed basin or sub-basin area. Sub-basin areas may in fact cover a large geographic area displaying a variety of terrain, vegetation covered patterns, soil types, etc. The natural resolution of various remotely sensed data is frequently much smaller than the sub-basin level. It is therefore possible to study a watershed area at a level much smaller than that currently used by the principal hydrological model. This capability to study a basin or a watershed on a variety of spatial levels promises to be a great aid to the application scientists.

5.5.2 Recommendations

As a result of the work performed under contract NAS5-22894 Earth Satellite Corporation recommends:

1. The implementation of the geocoded Hydrology Applications Data Management System be completed with emphasis directed towards the river forecast problem.

2. Potential hydrology application users be strongly encouraged to use the existing portions of the system to gain hands-on experience with their own hydrology problems.

Additionally, Earth Satellite scientists believe that while the specific details of this system design are currently directed toward the hydrology applications area the general design concept used here is applicable, and in fact directly transferable, to many other application areas. The geocoded data base is developed for the hydrology applications which are structurally similar to the agrometeorological data files used by the AGMET yield modeling systems developed at EarthSat. The interactive nature of the hydrology systems is certainly applicable to many other application areas including agronomy, forestry, and range land management to name only a few. EarthSat therefore recommends a consideration be given to broadening the scope of the hydrology activities to include other discipline areas.

APPENDIX A

SOFTWARE DOCUMENTATION

1.0 OVERVIEW

Appendix A contains documentation for all software items delivered under this contract. Source, objects, and task modules are all contained on the EarthSat RP04P disk pack, LABEL=ESC, under UIC [350,35]. The software items are divided into three categories:

1. General purpose subroutines,
2. Pre-existing software included on the deliverable items list of the contract,
3. Data management software developed specifically for the contract.

Documentation of categories two and three assumes familiarity with the subroutines included in category one.

Most of the software items consist of a main program which drives one or more subroutines. Each is documented in a separate module, but all module common to a task are grouped together and preceded by a functional description of that task.

Documentation for each modular includes the following:

1. Functional description
2. Description of argument list (if applicable)
3. Description of common areas
4. Description of variables
5. Flow chart

Unless otherwise specified all variables are INTEGER*2. Sort listings are not included in this appendix but are included in a separately bound file.

2.0 GENERAL PURPOSE SUBROUTINES

2.1 OPEN

Subroutine OPEN opens a file on disk, tape or refresh memory. It accepts an input/output flag and a logical unit number, and checks to see if the LUN is already open. It then prompts the operator for a device type and calls the appropriate subroutine (OPENMT, OPENRD, OPENIC) to open the file.

2.1.1 Argument List

- a. I0-input/output flag, equals 0 if file is for input, equals 1 if file is for output.
- b. LUN-Logical Unit Number.

2.1.2 COMMON Areas

- a. DCB
 1. LUNTAB (10) - Stores device type and I/O flag for up to 10 LUNS.
 2. FUNCT (10) - Stores QIO function for magnetic tape files.
 3. RECORD (10) - Stores current record number for refresh files.
 4. START (10) - Contains starting line number for refresh files.

2.1.3 Variables

- a. TYPE (3) - Stores device type codes (T,D,R) in ASCII.
- b. DEVICE - Stores desired device type in ASCII.

2.1.4 User's Guide

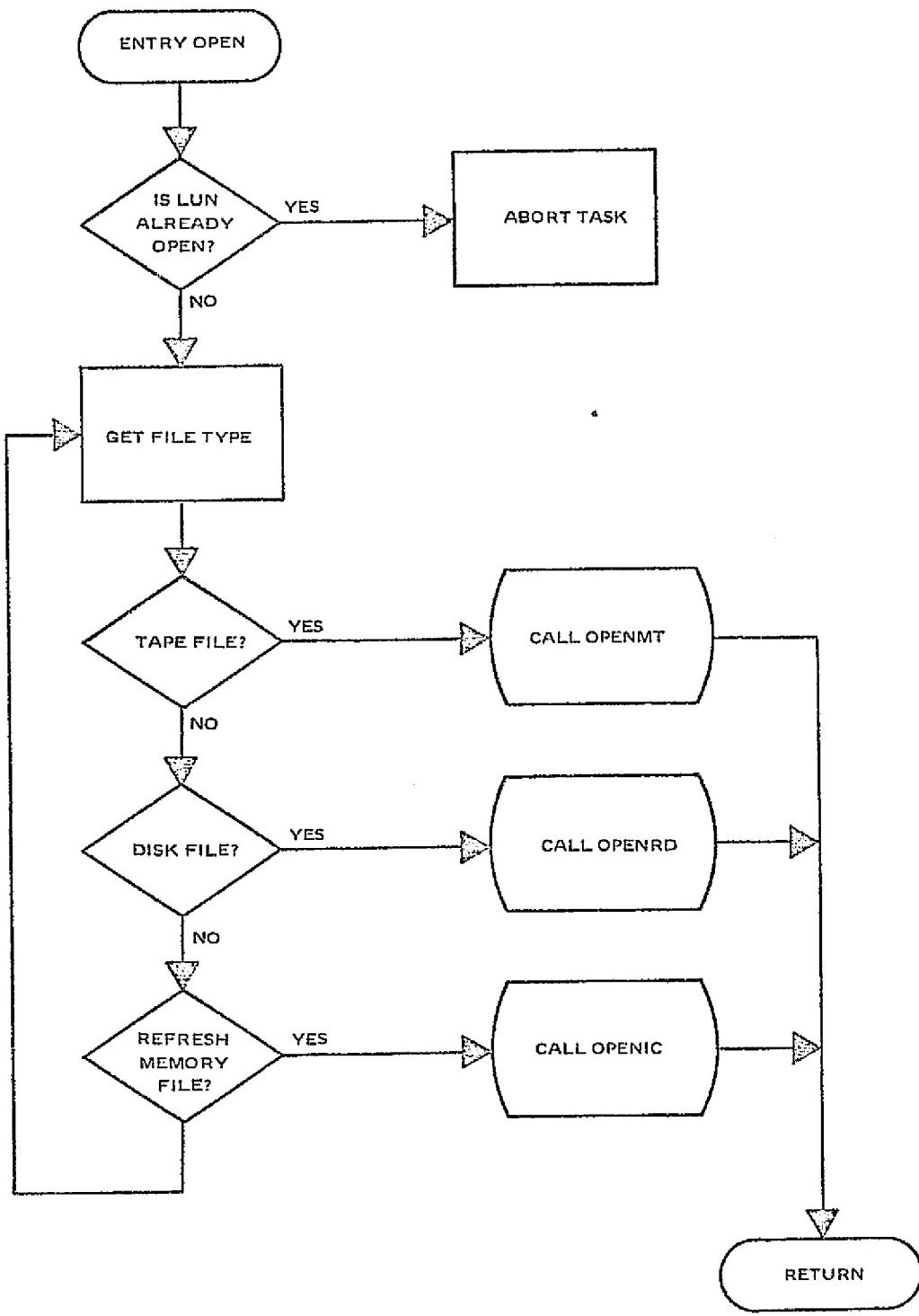
PROMPT

RESPONSE

OPENING LUN (1-10) FOR (INPUT/OUTPUT)

(T) APE, (D) ISK, OR (R) EFRESH? T, D, or R

OPEN



2.2 OPENMT

Subroutine OPENMT is called to open a magnetic tape file. First, it constructs a table entry to describe the file. This entry is of the form II_8 where $I = 0$ if the file is for input and $I = 1$ if the file is for output. Next, the user is prompted for the following information:

1. File number;
2. Tape density;
3. Maximum parity errors;
4. Physical number of the tape drive.

ASNLUN is then called to assign the LUN to the specified tape drive and the device is attached to the task to restrict access to the tape drive. QIO is called with a function of IOSMO to simultaneously set the tape characteristics and check for load point positioning. If the tape is not at load point, the characteristics will not be set and a fatal hardware error will result. At this point the user has the option of continuing or exiting. If he chooses to continue, the characteristics are set using the QIO function IOSTC which will not check for load point positioning. Finally, the tape is positioned to the desired file using the QIO function IOSPF.

2.2.1 Argument List

- a. IO - Equals 0 for input file, 1 for output file
- b. LUN - Logical Unit Number

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2.2.2 Common Areas

- a. DCB - see 2.1.2
- b. STAT -
 - 1. ISTAT (2) - I/O Status block
 - 2. IPRM (6) - QIO parameter list
 - 3. ISW - Directive status word
- c. IO -
 - 1. MAXPAR (10) - Maximum parity errors allowed

2.2.3 Variables

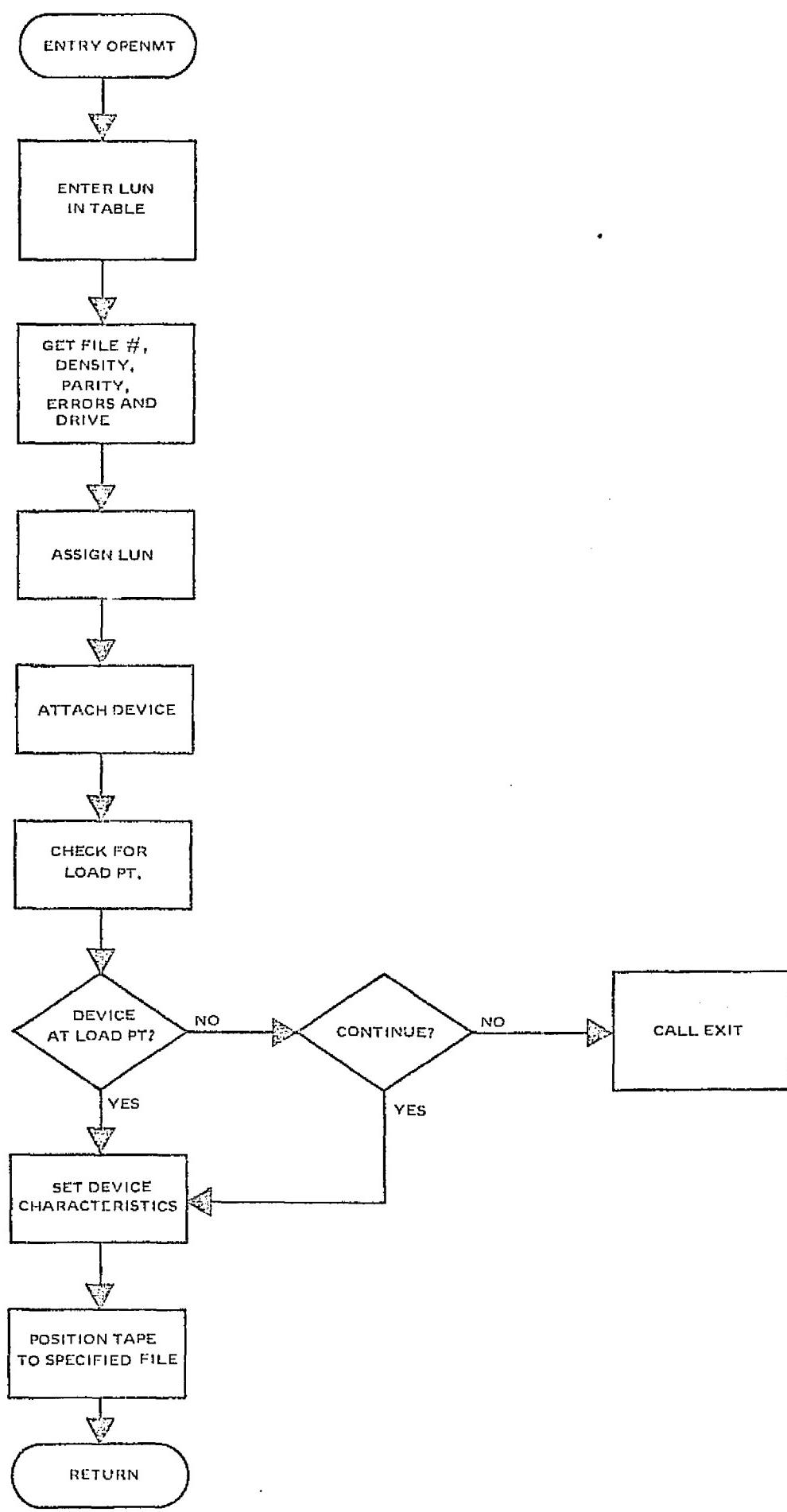
- a. IDEV - Stores ASCII, device name "MM"
- b. IOSMO - QIO function, set characteristics and verify load point positioning
- c. IOSTC - QIO function, set characteristics
- d. IOATT - QIO function, attach device
- e. IOSPF - QIO function, skip file
- f. NFILE - File number
- g. TDEN - Tape characteristics, octal mask
- h. DEN - Tape density, 800 or 1,600
- i. DNUM - Device number
- j. FLAG - Flag for IOSMO, equals 1 if LUN not at load point

2.2.4 User's Guide

| <u>PROMPT</u> | <u>RESPONSE</u> |
|----------------|------------------|
| FILE NUMBER = | positive integer |
| TAPE DENSITY = | 800 or 1,600 |

| <u>PROMPT</u> | <u>RESPONSE</u> |
|-------------------------|---|
| MAXIMUM PARITY ERRORS = | positive integer or carriage return for default of ten |
| TAPE DRIVE NUMBER = | 0 or 1 |

OPENMT



2.3 OPENRD

Subroutine OPENRD is called by OPEN to open a file on disk storage. First a table entry is constructed in the form $10I_8$, where I = 0 for an input file, 1 for output file. The user is prompted for a file name which must be prefaced by the device name if the file does not reside on SY:. The specified LUN is assigned to the file and control is returned to open.

2.3.1 Argument List

- a. IO - Equals 0 for input, 1 for output
- b. LUN - Logical Unit Number

2.3.2 Common Areas

- a. DCB - see 2.1.2
- b. STAT - see 2.2.2

2.3.3 Variables

- a. FILE (18) - Logical * 1, stores ASCII file name

2.3.4 User's Guide

| <u>PROMPT</u> | <u>RESPONSE</u> |
|--------------------------|---|
| DISK FILE NAME? > | 18-character file name, including device name if other than SY: |
| RECORD LENGTH (BYTES?) > | even positive integer |
| NUMBER OF RECORDS? > | to allocate disk storage, enter integer number of records. For no initial allocation, press carriage return |

2.4 OPENIC

Subroutine OPENIC is called by OPEN to open a refresh memory file and allow the user to specify a separate LUN for each channel. These are dummy LUN's, as only one may be assigned to IC: and this is done at task build. Each dummy LUN points to the real LUN which along with the channel number defines the location of the file.

OPENIC constructs a table entry into LUNTAB in the form 1000CI)₈ where C = channel number, I = 0 for input and 1 for output. The user is prompted for starting line number to define the absolute position of the file. Any subsequent REREAD commands will position the file to this line number. Finally, the file pointer is set equal to the start line to position the file at its beginning.

2.4.1 Argument List

- a. IO - 0 for input, 1 for output
- b. LUN - Logical Unit Number

2.4.2 Common Areas

- a. DCB - see 2.1.2

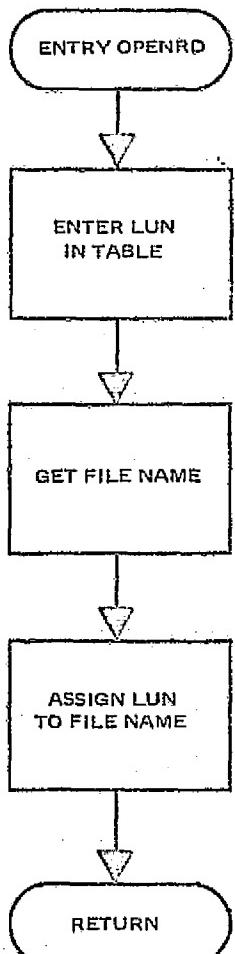
2.4.3 Variables

- a. CHAN - Channel number

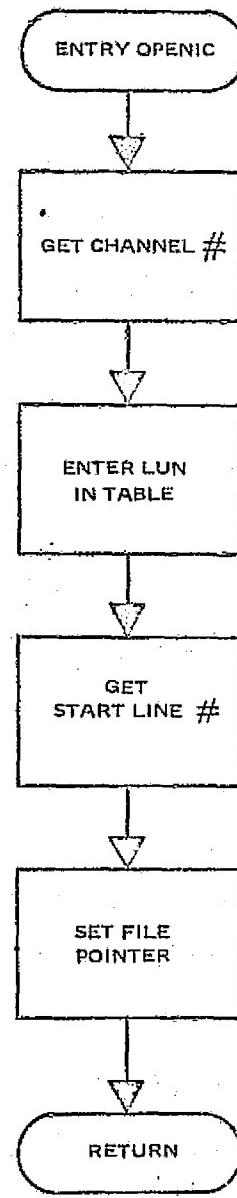
2.4.4 User's Guide

| PROMPT | RESPONSE |
|-----------------------|------------------------------|
| CHANNEL NUMBER? > | 1-5 |
| STARTING LINE NUMBER? | 0-511 or carriage return for |
| (DEFAULT EQUALS 70) > | default |

OPENRD



OPENIC



2.5 READER

Subroutine READER is called to read a block of data from the specified file. The file type is extracted from LUNTAB which determines how the record is read. For a tape file, a QIO directive (IORLB) is issued; for refresh memory, IRV is called and a record pointer is incremented. Disk I/O is accomplished through a call to FVREAD.

2.5.1 Argument List

- a. LUN - Logical Unit Number
- b. BUFFER - I/O buffer
- c. BUflen - Buffer length in words

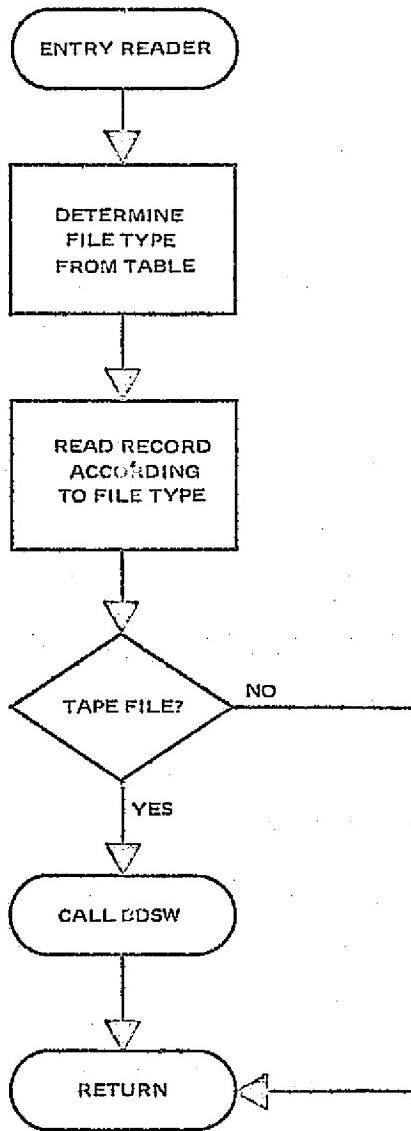
2.5.2 Common Areas

- a. DCB - see 2.1.2
- b. STAT - see 2.2.2

2.5.3 Variables

- a. IORLB - QIO function, read logical block

READER



2.6 WRITER

Subroutine WRITER is called to write a block of data to a specified file. The file type is extracted from LUNTAB which determines how the record is written. For a tape file a QIO directive (IOWLB) is issued; for refresh memory IWF is called and the record pointer is incremented, and disk I/O is accomplished through a call to FVWRIT.

2.6.1 Argument List

- a. LUN - Logical Unit Number
- b. BUFFER - I/O buffer
- c. BUflen - Buffer length (words)

2.6.2 Common Areas

- a. DCB - see 2.1.2
- b. STAT - see 2.2.2

2.6.3 Variables

- a. IOWLB - QIO function, write logical block

2.7 REREAD

Subroutine REREAD positions the specified file to a starting point. For a tape file, the QIO directive IOSPF is issued with a parameter of -1 to skip to the last EOF mark encountered. Positioning that may refresh file is accomplished by resetting the record pointer to the starting line number. Positioning of a disk file is accomplished through a call to FVDSET with an argument of 1.

2.7.1 Argument List

- a. LUN - Logical Unit Number

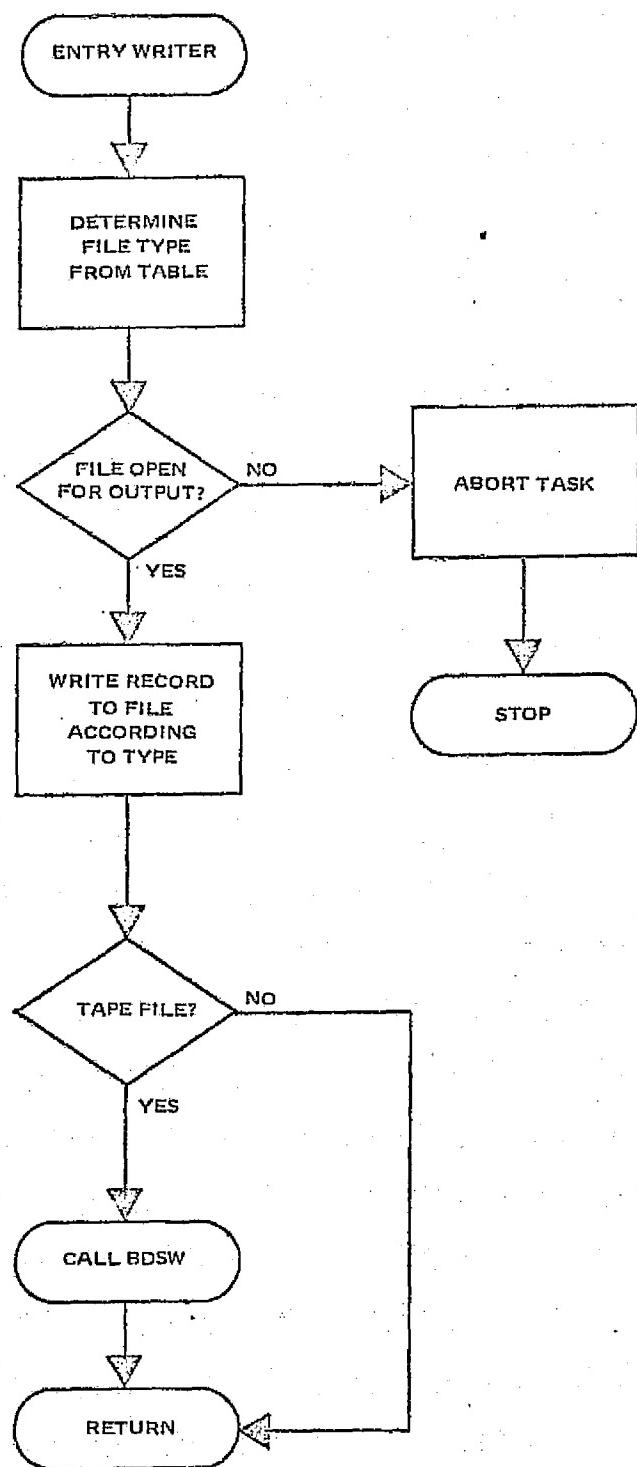
2.7.2 Common Areas

- a. DCB - see 2.1.2
- b. STAT - see 2.2.2

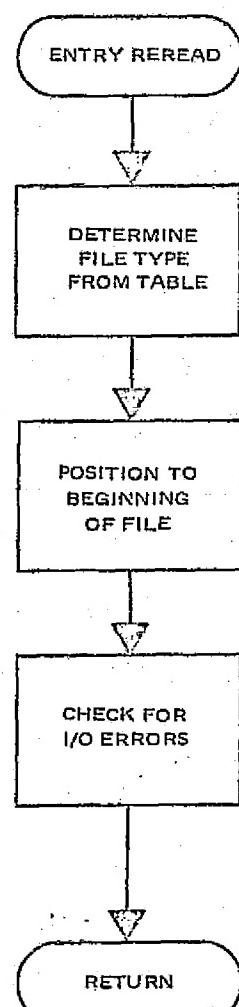
2.7.3 Variables

- a. IOSPF - QIO function, skip EOF mark

WRITER



REREAD



2.8 RWND

Subroutine RWND is essentially the same as REREAD for refresh, disk, or single file magnetic tape. However, for a multi-file magnetic tape RWND positions to the load point rather than the beginning of the current file.

2.8.1 Argument List

- a. LUN - Logical Unit Number

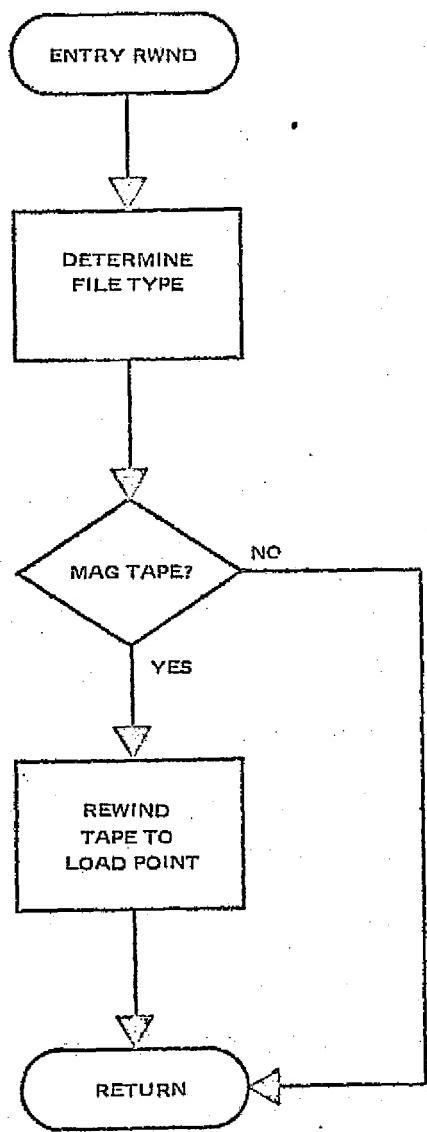
2.8.2 Common Areas

- a. DCB - see 2.1.2
- b. STAT - see 2.2.2

2.8.3 Variables

- a. IORWD - QIO function, rewind tape

RWND



2.9 EOF

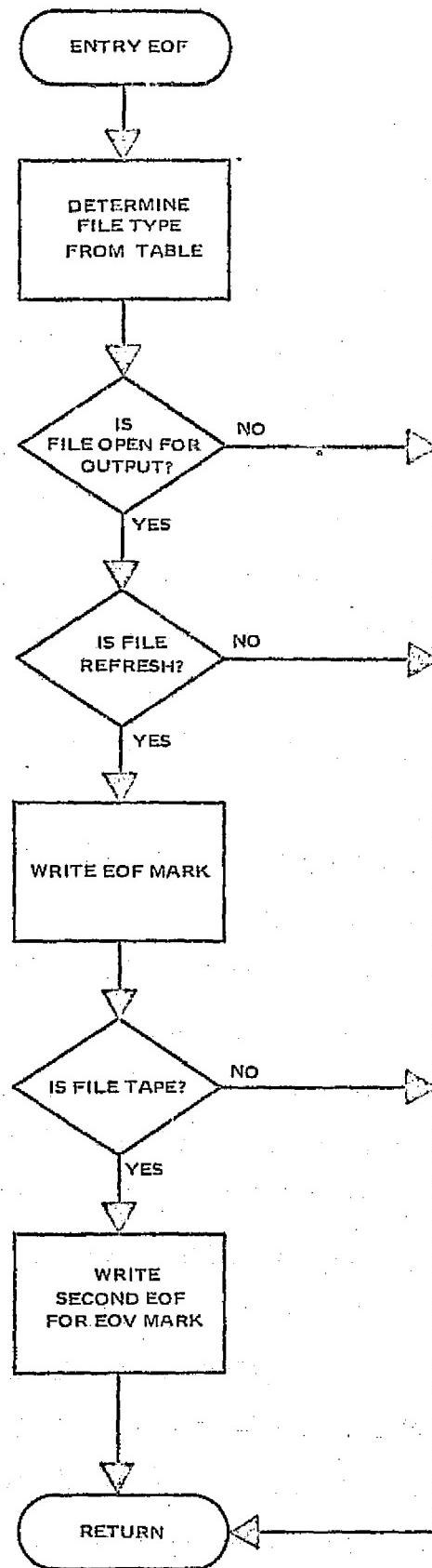
Subroutine EOF checks to see if the specified LUN has been opened for output and if so writes an end-of-file mark. For a magnetic tape, two marks are written to indicate EOF. This is accomplished by issuing two successive QIO requests (IOEOF). For a disk file or refresh file, control is simply returned to the calling routine.

2.9.1 Argument List

- a. LUN - Logical Unit Number

2.9.2 Common Areas

- a. DCB - see 2.1.2
- b. STAT - see 2.2.2



2.10 WAIT

Subroutine WAIT is called after an asynchronous I/O request to wait for the event flag associated with specified LUN. For a refresh file ICWAIT, a system subroutine which waits for the event flag associated with IC:, is called. For magnetic tape WAITFR a system subroutine which waits for a specified event flag is called with an argument of 10. The LUN is used to point into FUNCT which contains codes describing which I/O function was last performed on each unit. This information is then passed to the QIO error handling routine, BDSW and BDSTAT. A disk file is synchronized through a call to FVWAIT.

2.10.1 Argument List

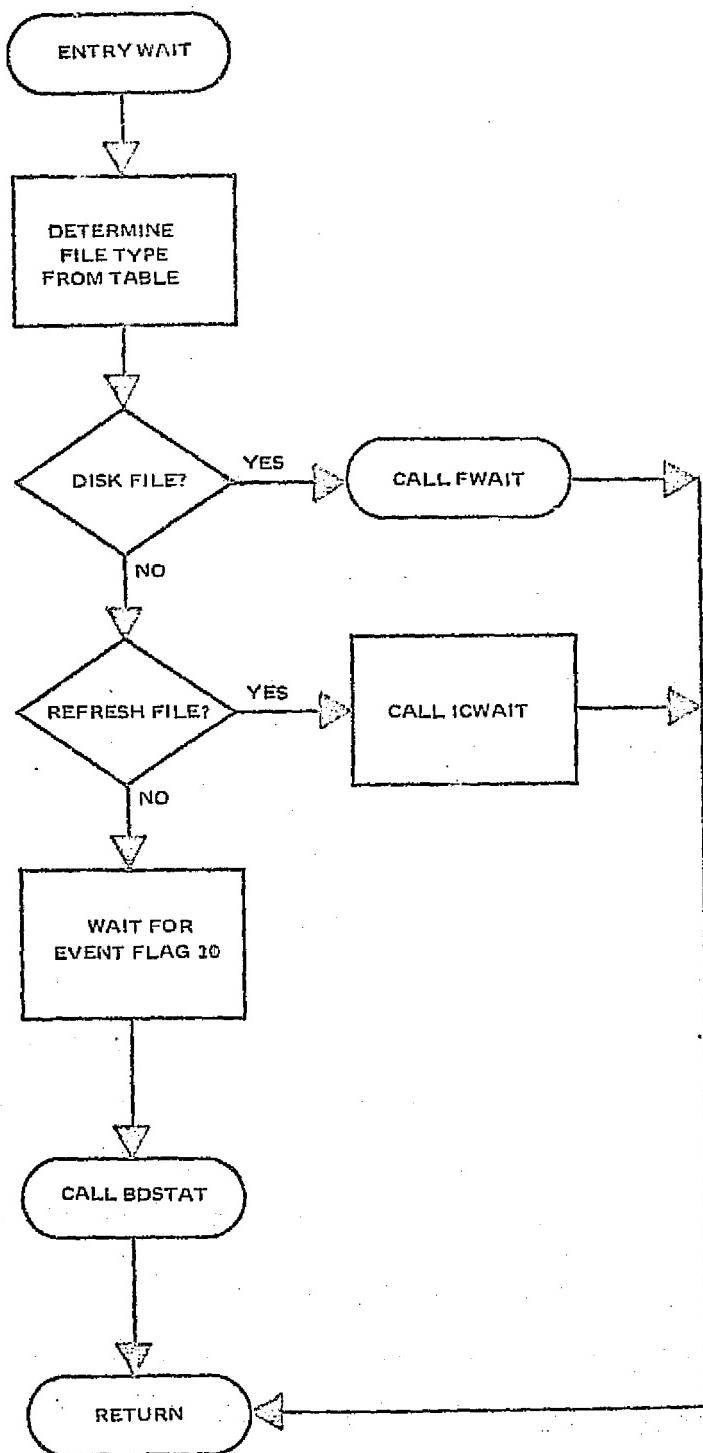
- a. LUN, Logical Unit Number
- b. FLAG - EOF flag equals on encountering end-of-file

2.10.2 Common Areas

- a. DCB - see 2.1.2
- b. STAT - see 2.2.2

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WAIT



2.11 SET

Subroutine SET is used to set an event flag associated with a specified LUN. This is accomplished through a call to system subroutine SETEF. For magnetic tape file SETEF is called with an argument of 10; for refresh memory SET is called with an argument of 23, and for a disk file SETEF is called with an argument which is one greater than the logical unit number.

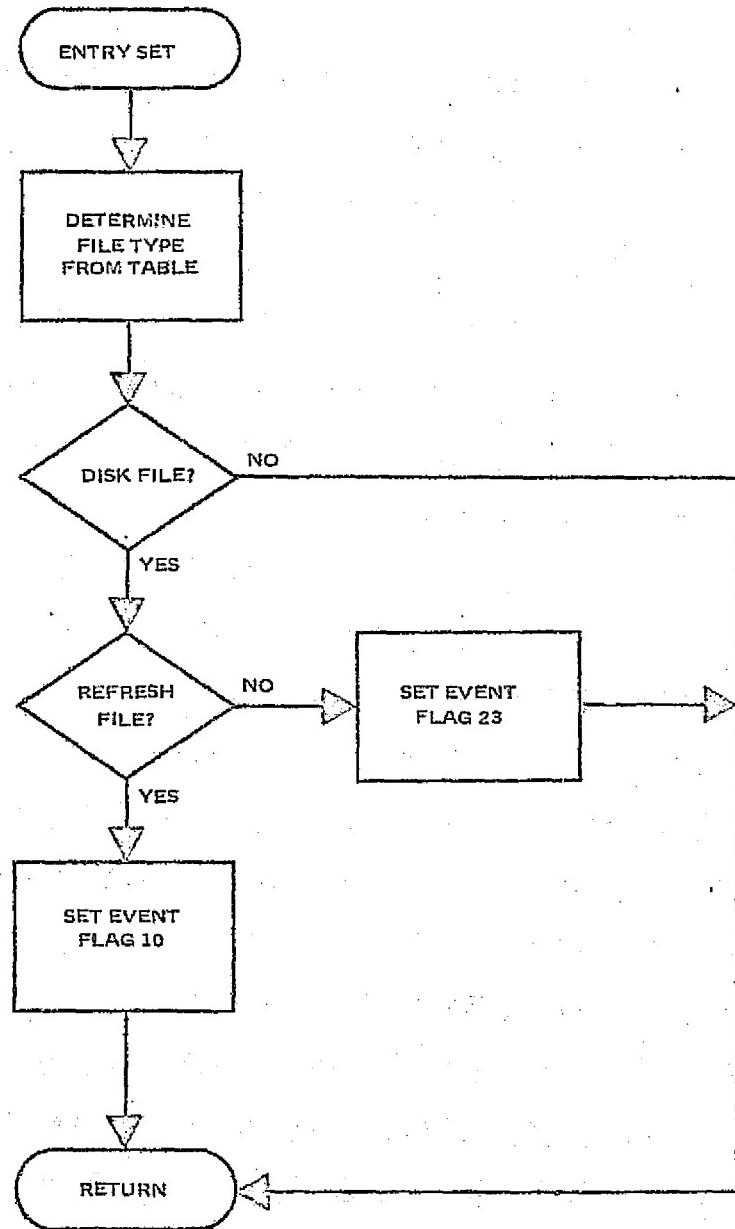
2.11.1 Argument List

- a. LUN - Logical Unit Number

2.11.2 Common Areas

- a. DCB - see 2.1.2
- b. STAT - see 2.2.2

SET



2.12 SKIP

Subroutine SKIP is called to space forward or backward a specified number of records. For a refresh file the number of records to be skipped is added to the record pointer. For a magnetic tape the number of records to be skipped is entered in the first word of the parameter list and a QIO request (IOSPB) is issued. After waiting for completion of request the QIO error checking routines are called. Disk file positioning is accomplished by converting the number of records to virtual block number and passing the block number to FVDSET.

2.12.1 Argument List

- a. LUN - Logical Unit Number
- b. NSKIP - Number of records to be skipped

2.12.2 Common Areas

- a. DCB - see 2.1.2
- b. STAT - see 2.2.2

2.12.3 Variables

- a. IOSPB - QIO Function, SKIP block
- b. VBN - Virtual Block Number

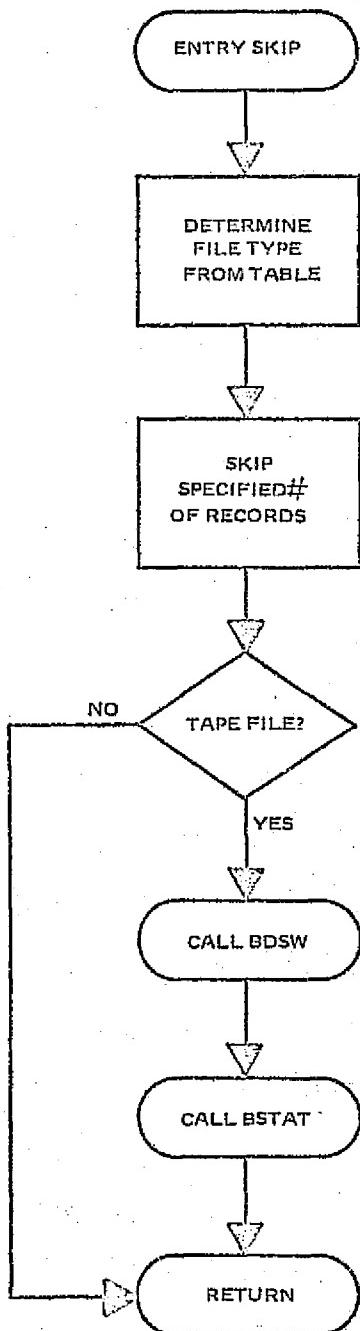
2.13 UNPK

Subroutine UNPK is called by reader and writer for refresh files only. This module extracts the channel number from LUNTAB by shifting LUNTAB (LUN) three bits to the right, and then performing a logical OR with a mask which has only the three lower bits turned on.

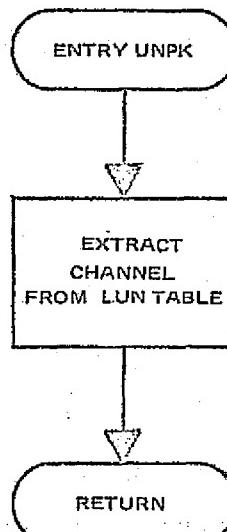
2.13.1 Argument List

- a. WORD - Logical Unit Number table entry

SKIP



UNPK



2.14 BDSW

Subroutine BDSW is called to check for errors in the directive status word (DSW). The DSW indicates the success or failure of a queue I/O request only. A "1" in the directive status word indicates that the request was successfully queued. It contains no information about the status of the I/O function itself.

If the DSW equals one, BDSW returns with no action taken. If the DSW is negative, an error message is typed on the terminal and control is transferred to the executive through the system subroutine EXIT.

2.14.1 Argument List

- a. EVENT - I/O function code
- b. LUN - Logical Unit Number

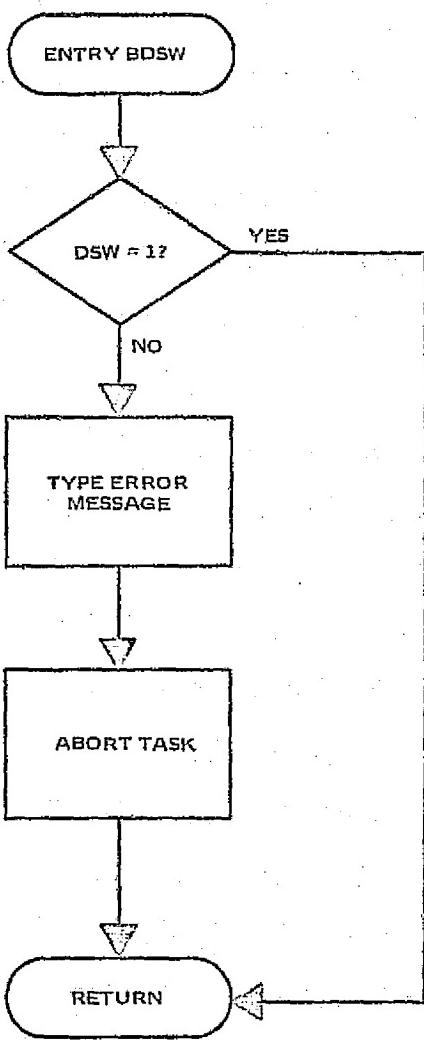
2.14.2 Common Areas

- a. IO see 2.2.2
- b. STAT see 2.2.2

2.14.3 Variables

- a. FCODE (10,3) - Used to store the ASCII characters for the 10 possible QIO functions

BDSW



2.15 BDSTAT

Subroutine BDSTAT is called after a successful I/O queue to check the I/O status block. If the I/O request was executed normally, ISTAT(1) equals one. BDSTAT first checks for a status word of one; if it is found control returns to the calling program. Next it checks for an end-of-volume error, ("365) which if found is ignored. If an EOF error is not detected the function code is checked. If any function other than IOSMO (set tape characteristics and verify load point) or IORLB (read logical block) is found, an error message is typed on the terminal and control is transferred to the executive through the system subroutine EXIT.

If the function is IOSMO, BDSTAT checks for a fatal hardware error, (IEFHE), which is the error returned if the tape is not at load point. If IEFHE is detected the user is notified and asked if he desires to continue or terminate. At this point the user may manually position the tape or take other appropriate action. If he desires to continue control is returned to OPENMT with a FLAG equal to minus one. This indicates to OPENMT that it should issue an IOSETC request to set the characteristics without verifying load point positioning. If an error other than IEFHE is detected the task is terminated and an error message is typed on the terminal.

If the device function is IORLB, BDSTAT checks first for the error IEDAO which indicates that the record length exceeded buffer area. If found this error is ignored and control is returned to the calling program. Next the status block is checked for IEEOF which indicates end-of-file. If this is found, FLAG is set to minus one and control is returned to the calling program. If IEEOF is not detected the status

word is checked for IEVER which indicates a parity error. If found the parity error count is incremented and compared with the maximum allowable number. If the maximum number of parity errors is exceeded an error message is typed and the task exits. Otherwise control returns to the calling routine. Any other error message resulting from an IORLB is considered unconditionally fatal and results in abnormal termination of the task with an appropriate error message.

2.15.1 Arguments

- a. EVENT - I/O function code used to point into FCODE
- b. LUN - Logical Unit Number
- c. FLAG - Equals minus one to indicate an error which should be handled by calling routine

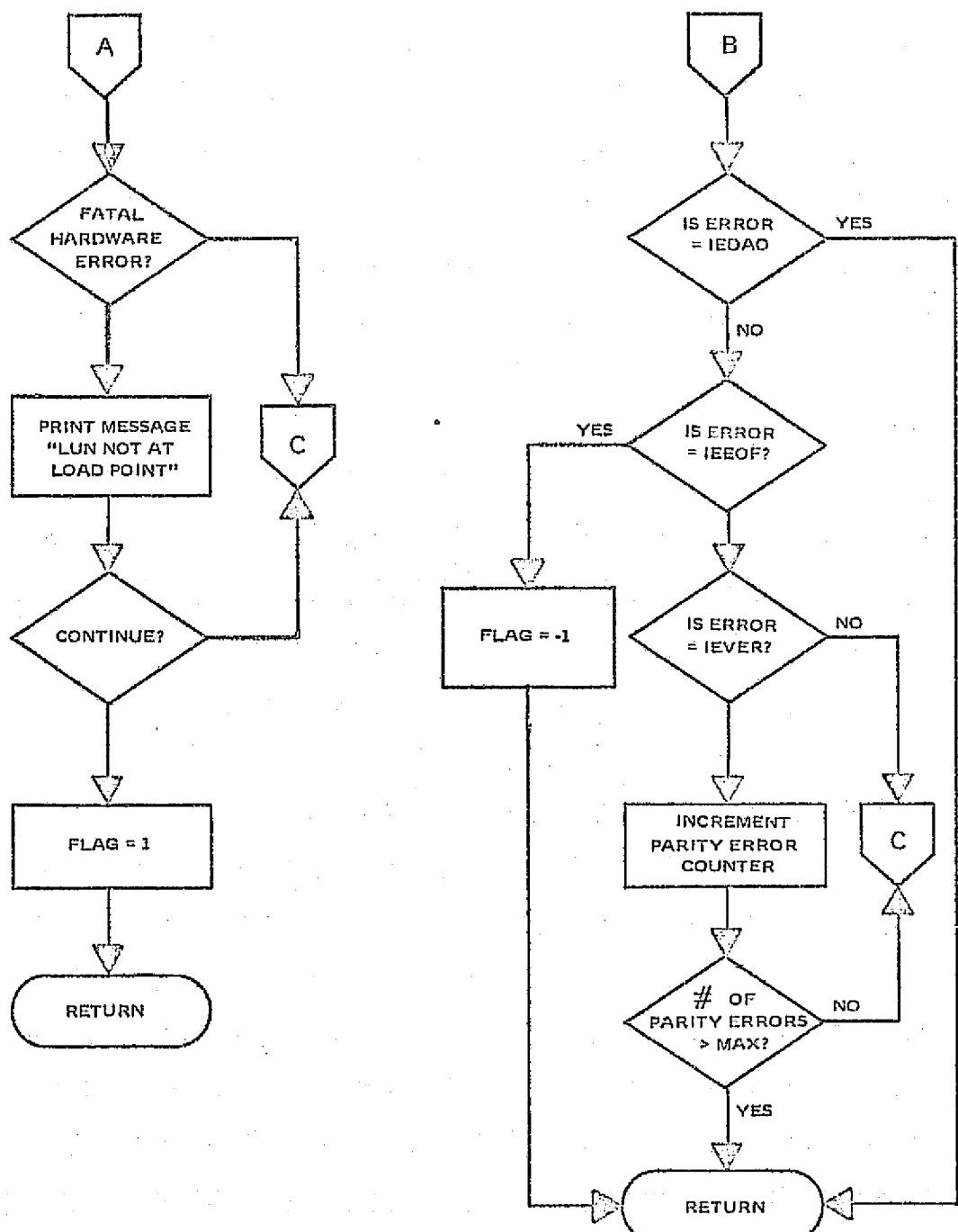
2.15.2 Common Areas

- a. IO - see 2.2.2
- b. STAT - see 2.2.2

2.15.3 Variables

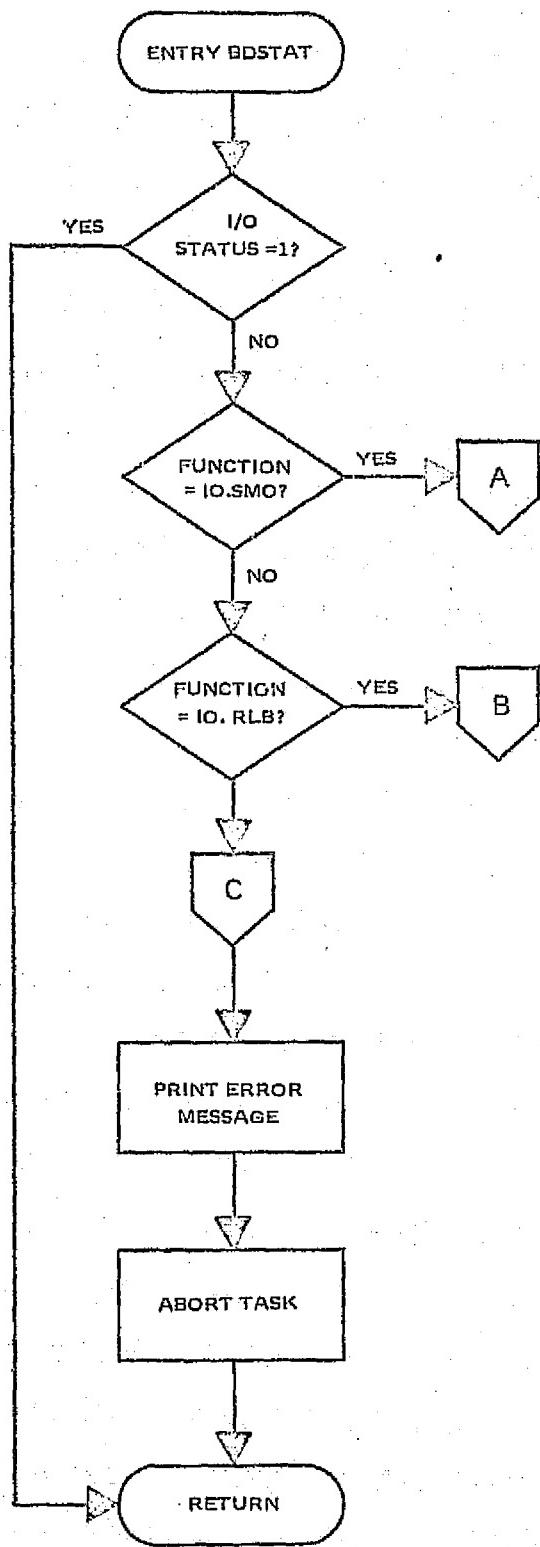
- a. FCODE (10,3) - stores ASCII characters for the 10 QIO function codes
- b. NPAR (10) - contains the number of parity errors encountered on LUN's 1-10
- c. MASK - logical mask, high order byte off, low order byte on
- d. IEFHE - error code, fatal hardware error

- e. IEDAO - error code, record length exceeds buffer
- f. IEEOF - error code, end-of-file
- g. IEVER - error code, parity error



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BDSTAT



2.16 GTWND

Subroutine GTWND is an interface routine which prompts the user for the window coordinates of an input image.

2.16.1 Argument List

- a. FROW - first row
- b. NROWS - number of rows
- c. FCOL - first column
- d. NCOLS - number of columns

2.16.2 Common Areas

None

2.16.3 Variables

None

2.16.4 User's Guide

| <u>PROMPT</u> | <u>RESPONSE</u> |
|------------------------|-----------------|
| START ROW NUMBER? > | Integer |
| START COLUMN NUMBER? > | Odd Integer |
| NUMBER OF ROWS? > | Integer |
| NUMBER OF COLUMNS? > | Even Integer |
| CONTINUE? > | Y or N |

3.0 APPLICATIONS SOFTWARE

3.1 GRAY

GRAY is a multi-purpose task which allows the user to modify the gray scale of an image in a number of ways including:

1. Linear transformation
2. User defined transformation
3. Histogram equalization

In addition to its image enhancement capabilities, GRAY can also be used for image contouring or density slicing.

Separate versions of GRAY are available for the 11/70 and the Image 100. The 11/70 version is described in the following sections and the Image 100 modifications are outlined in Section 3.1.10.

3.1.1 MAIN

The function of MAIN is to prompt for the desired option, check to see that processing is proceeding in the correct sequence, and call the required sub-routines to perform the processing. Five options are recognized:

1. SCAN - scan the input image
2. FUNCTION - define a gray scale transform
3. PICTURE - produce a transformed image
4. OVERRIDE - override processing order
5. STOP

The correct processing order for most applications is SCAN, FUNCTION, PICTURE, STOP. If it is desirable to omit the SCAN or FUNCTION steps, the OVERRIDE option must be used.

3.1.1.1 Common Areas

A. MAXMIN

1. MINORG - original minimum gray value
2. MAXORG - original maximum gray value
3. MINFNL - final minimum gray value
4. MAXFNL - final maximum gray value

B. WNDW

1. IRB - first row
2. IRE - last row
3. ICB - first column
4. ICE - last column
5. INC - scan increment

C. SCALE

1. ISCL(256) - gray scale transformation vector

D. LUN

1. TIN - input image LUN
2. TOUT - output image LUN
3. NIN - control terminal LUN
4. NOUT - line printer LUN

3.1.1.2 Variables

A. KSCAN - scan flag

B. KFUNC - function flag

3.1.2 INIT

Sub-routine INIT is called by MAIN to initialize the variables and arrays in common blocks MAXMIN, SCALE, LUN, and VECT.

3.1.2.1 Argument List - None

3.1.2.2 Common Areas

- A. MAXMIN - see 3.1.1.1
- B. SCALE - see 3.1.1.1
- C. LUN - see 3.1.1.1
- D. VECT
 - 1. INTHIS(256) - input histogram
 - 2. FNLHIS(256) - transformed histogram

3.1.3 ISCAN

Sub-routine ISCAN calls GTWND to get the window coordinates, prompts the user for the scan increment and then calls SCAN (see 3.2.2) to obtain a histogram of the input image.

Before returning, ISCAN calls HHIST (see) to produce a display of the histogram on the line printer.

3.1.3.1 Argument List - None

3.1.3.2 Common Areas

- A. WNDW - see 3.1.1.1
- B. SCALE - see 3.1.1.1
- C. LUN - see 3.1.1.1
- D. VECT - see 3.1.2.2

3.1.3.3 Variables

- A. INC - scan increment
- B. NROWS - number of rows of input
- C. NCOLS - number of columns of input

3.1.4 GRYSCL

Sub-routine GRYSCL allows the user to define the desired gray scale transformation, using one of five available options.

Option 1 defines an identity transformation where the output image is identical to the input image.

Option 2 allows the user to manually specify the desired transformation through the control terminal. This option is used for density slicing or contouring.

Option 3 accepts an initial and a final gray value range, then defines a linear transformation to stretch or compress the initial range to the final range.

Option 4 is a dummy option provided for future expansion of the program.

Option 5 allows the user to specify a spread factor in the form of percent of final range. It then calculates the mean and standard deviations above and below the mean of the original histogram. A linear transformation is then defined such that the gray values within one standard deviation of the mean are mapped into the range specified by the spread factor. This option requires an initial scan.

Option 6, known as histogram equalization, attempts to produce a flat histogram by aggregating the gray values in sparsely populated regions of the histogram while spreading densely populated gray values. This option requires an initial scan.

3.1.4.1 Argument List

- A. NBR - option number

3.1.4.2 Common Areas

- A. SCALE - see 3.1.1.1
- B. VECT - see 3.1.2.2
- C. MAXMIN - see 3.1.1.1

3.1.4.3 Variables

- A. ISTD - spread factor for Option 5
- B. IMEAN - original histogram mean
- C. SLOW - REAL*4, standard deviation below mean
- D. SUPP - REAL*4, standard deviation above mean
- E. MEANF - final mean of histogram

3.1.5 SLICER

Sub-routine SLICER is called by GRYSCL when Option 2 is specified. It allows the user to enter the desired gray scale transformation by typing a gray value followed by a repetition factor. This reduces the possibility of having to type in 256 separate gray values.

3.1.5.1 Argument List - None

3.1.5.2 Common Areas

- A. SCALE - see 3.1.1.1

3.1.6 HISEQL

Sub-routine HISEQL is called by GRYSCL when Option 6 is specified. From the input histogram it calculates the average.

number of pixels per gray value, then aggregates sparse population values to bring them up to the average. It also spreads the densely populated values so that a gray value with a population of N times the average will be followed by N-1 unpopulated values.

3.1.6.1 Argument List

- A. MINFNL - minimum final gray value
- B. MAXFNL - maximum final gray value
- C. INTTHIS(256) - input histogram
- D. ISCL(256) - gray scale transformation vector

3.1.6.2 Common Areas - None

3.1.6.3 Variables

- A. NGV - number of gray values in output range
- B. ISUM - histogram population
- C. GV - REAL*4, transformed gray value

3.1.7 PICT

Sub-routine PICT is called by MAIN when the PICTURE option is specified. It calls GTWND to get the window coordinates, then calls LITTON which generates the output image.

3.1.7.1 Argument List - None

3.1.7.2 Common Areas

- A. WNDW - see 3.1.1.1

3.1.7.3 Variables

- A. NROWS - number of rows to be processed
- B. NCOLS - number of columns to be processed

3.1.8 LITTON

Sub-routine LITTON is called by PICT. It reads the input image and applies the gray scale transformation to produce the output image.

3.1.8.1 Argument List - None

3.1.8.2 Common Areas

- A. WNDW - see 3.1.1.1
- B. SCALE - see 3.1.1.1
- C. LUN - see 3.1.1.1

3.1.9 User's Guide

GRAY is initiated by the MCR command RUN GRAY\$. In addition to the information required by OPEN (see 2.1.4) and GTWND (see 2.16.4), the user will be prompted for the following information.

| <u>PROMPT</u> | <u>RESPONSE</u> |
|-----------------------|---|
| OPTION = | SCAN, FUNCTION, PICTURE, OVERRIDE, or STOP |
| For option = SCAN | |
| SCAN INCREMENT?> | Positive integer |
| For option = FUNCTION | |
| GRAYSCALE OPTION#?> | 1, 2, 3, 5, or 6 |

For option #2

?>

Gray value (0-255), Repetition factor (1-256)

For option #3

TYPE IN ORIGINAL MINIMUM AND MAXIMUM GRAY VALUES >

Integer (0-255), Integer (0-255)

TYPE IN FINAL MINIMUM AND MAXIMUM GRAY VALUES >

Integer (0-255), Integer (0-255)

For option #5

SPREAD FACTOR? >

Integer (1-100) or carriage return for default of 66%

3.1.10 IMAGE-100 Modifications

For use on the IMAGE-100 System several modifications were made in GRAY. In ISCAN the scanning window is read from the cursor and up to four channels may be scanned at once. To be prompt

SCAN CHANNEL (1-4)? >

the user should respond with a carriage return if scanning is desired and any non-blank character if it is not. If the override option is used the user should respond similarly to the

ADJUST CHANNEL (1-4)? >

request. Modifications were also made to HISEQL in order to achieve the optimum results on the Image-100.

To histogram equalize a three-band, color, LANDSAT composite, the user should first adjust the color mix to his personal preference. Next he should run GRAY, scanning the three channels with image data. Next the FUNCTION OPTION should be selected and in response to the prompt

STEP WEDGE ON CHANNEL? >

the one unused channel (1-4) should be entered. After option six is selected, GRAY will ask the user to divide the output gray scale into three regions with the following prompts

MINIMUM OUTPUT VALUE? >

FIRST CUTOFF? >

SECOND CUTOFF? >

MAXIMUM OUTPUT VALUE? >

These values may be entered either by typing in a value or by placing the cursor of the desired point of the step wedge and pressing the carriage return. The first cutoff should be in the region where the transition from black to gray begins. The second cutoff should be in the region where no more change in brightness can be detected. Good results can be achieved by setting the maximum and minimum values at 0 and 150 respectively. Finally GRAY will prompt with

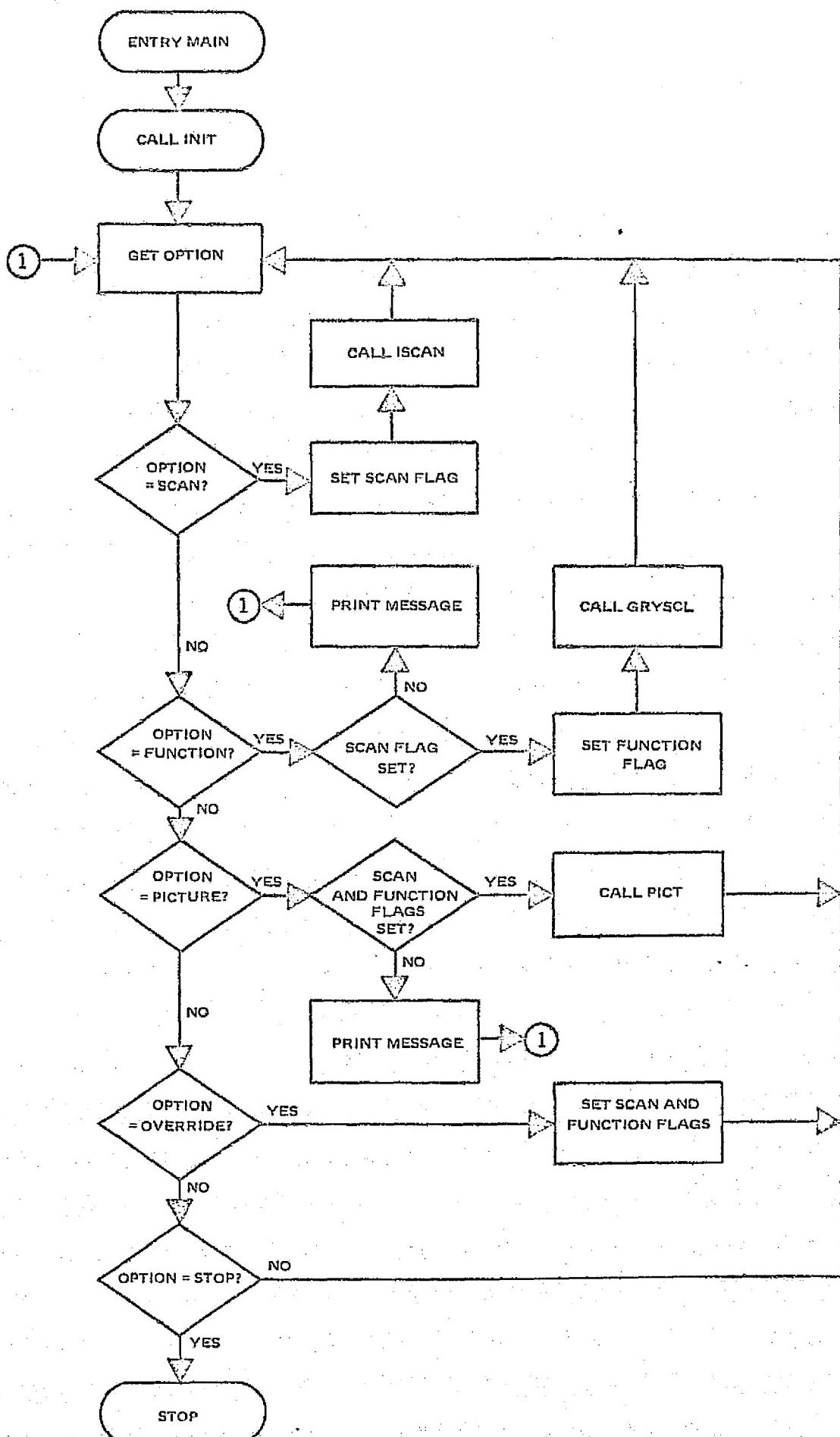
PERCENT BEFORE FIRST CUTOFF? >

PERCENT AFTER SECOND CUTOFF? >

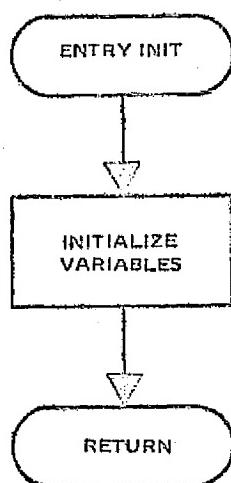
Good results can be achieved by responding with ten to both prompts but experimentation is encouraged.

GRAY will proceed to histogram equalize the first N percent of the input histogram to the range founded by the minimum value and the first cutoff, the last N percent to the range between the second cutoff and the maximum value, and the remainder of the input histogram to the range between the two cutoffs. N and M are the numbers which are typed in response to the percent before first cutoff and percent after second cutoff prompt respectively. The effect is to equalize most of the histogram in the area of maximum transition on the screen of the Image-100.

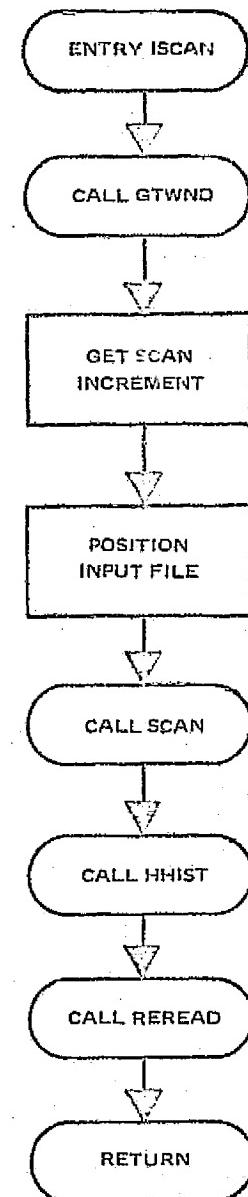
The PICTURE OPTION will then apply transformation to all three channels. Output is to the original channel, therefore the original data is lost.



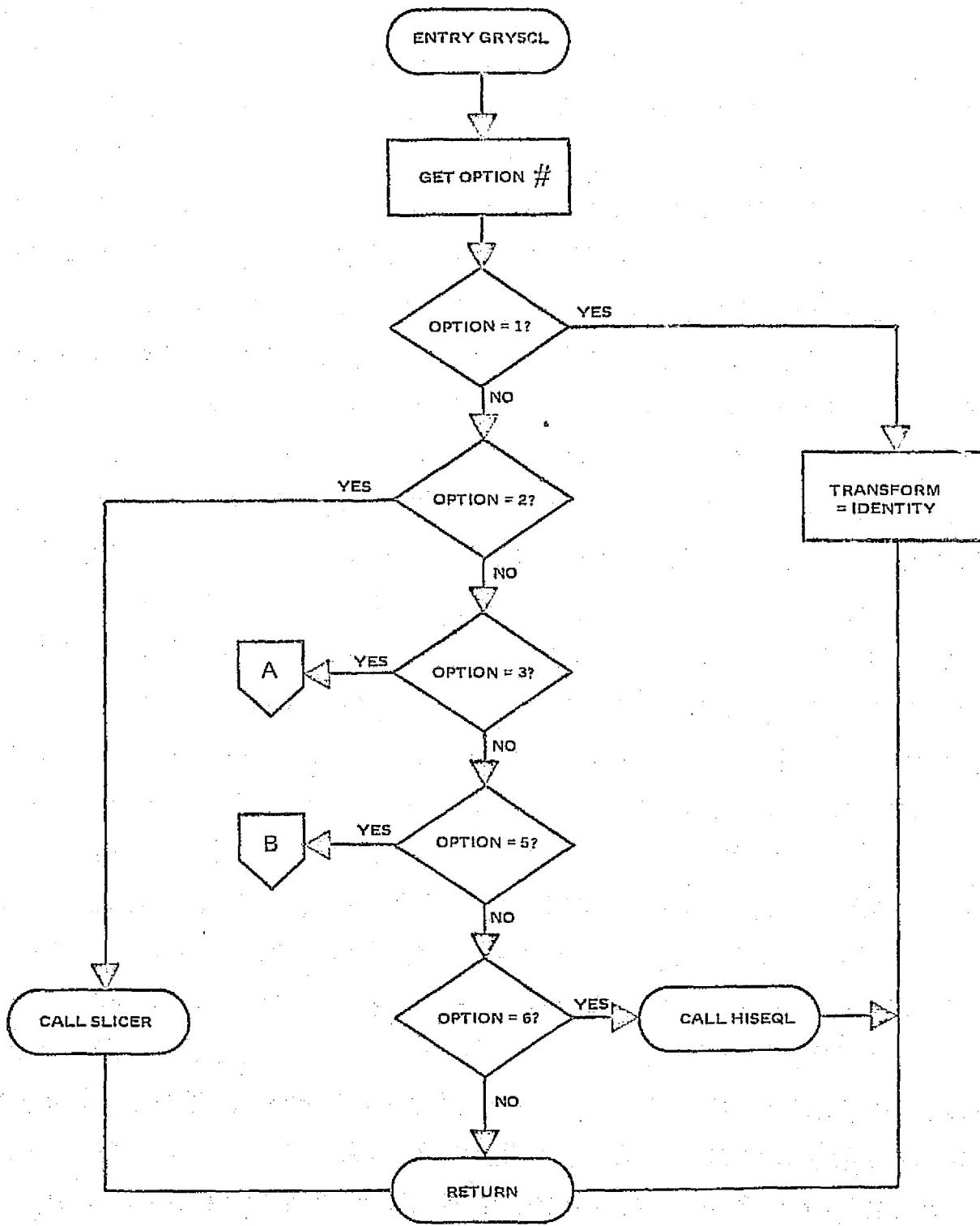
SUBROUTINE INIT



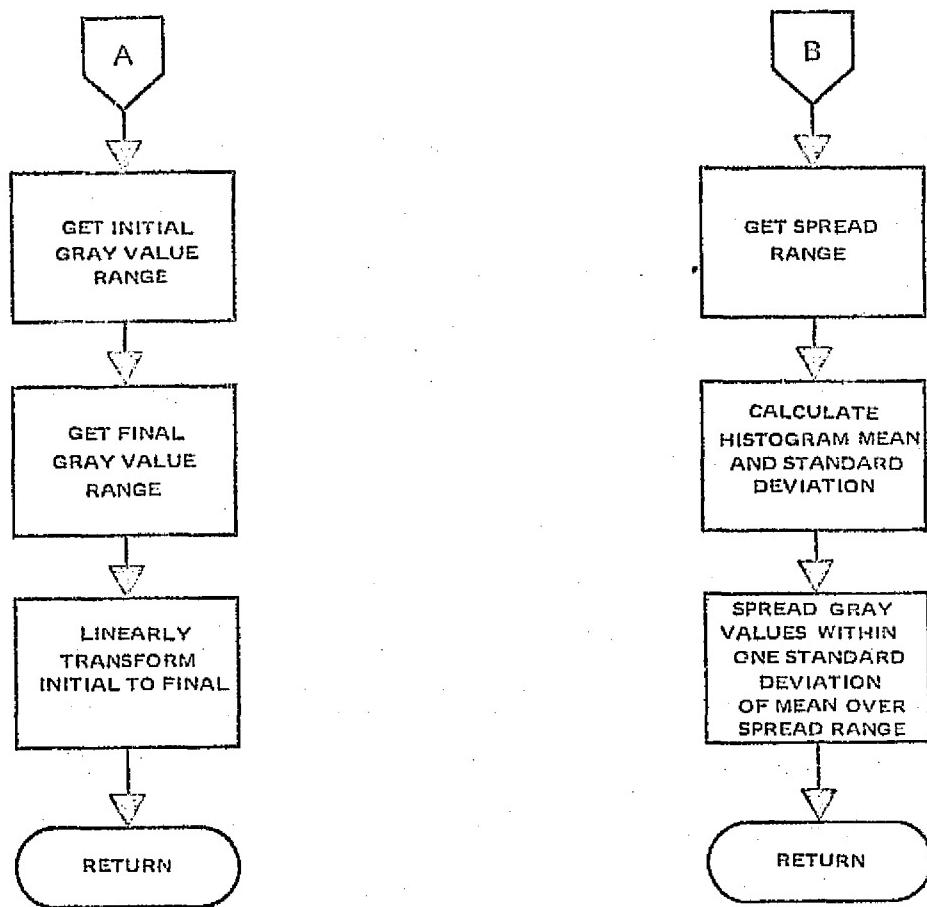
SUBROUTINE ISCAN



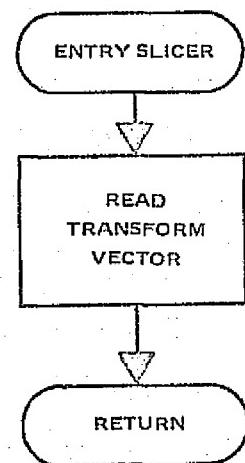
GRYSCL



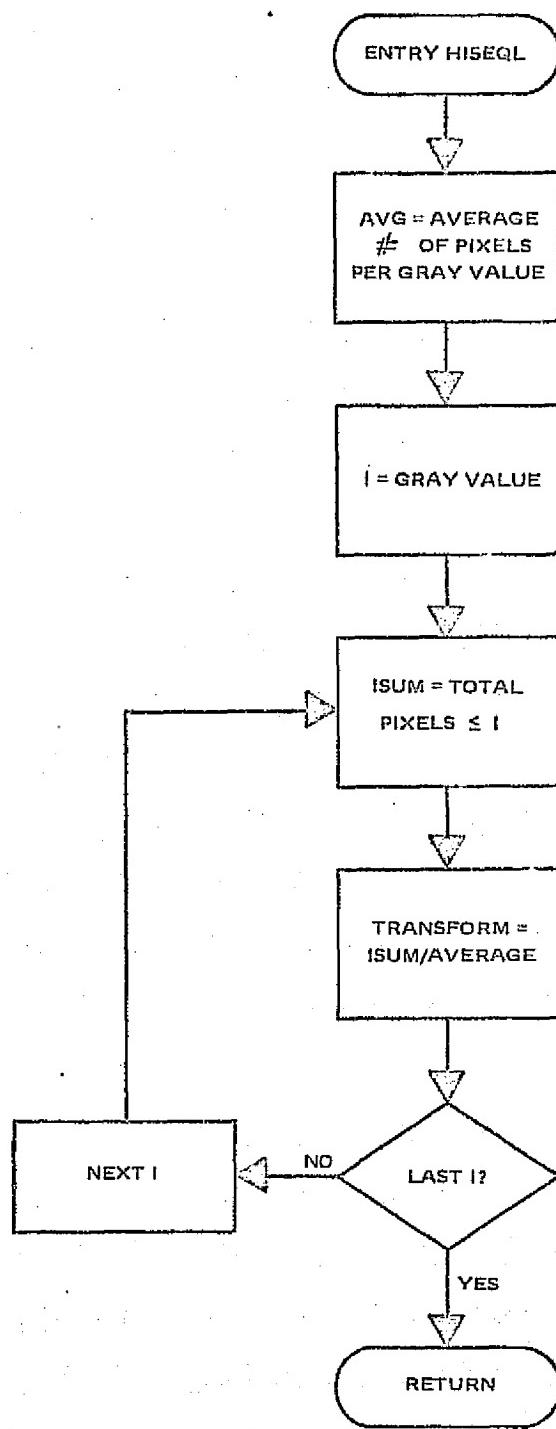
GRYSCL



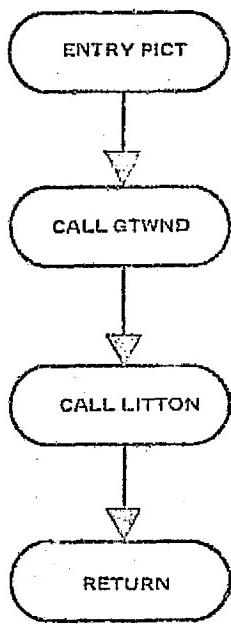
SLICER



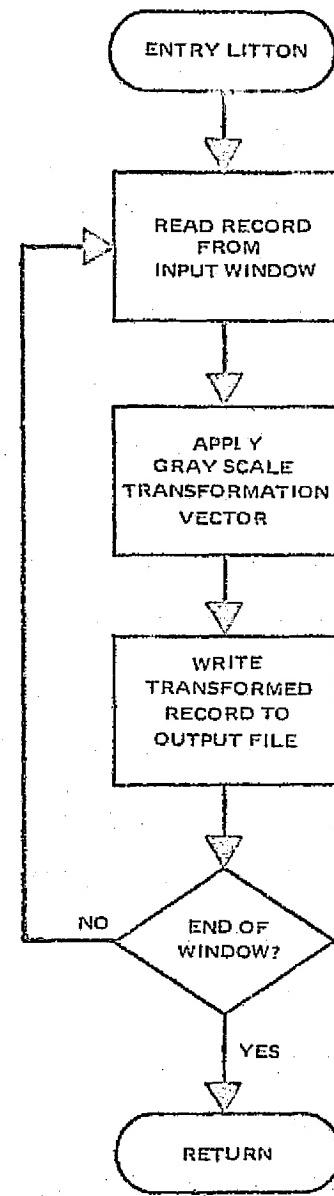
SUBROUTINE HISEQL



SUBROUTINE PICT



SUBROUTINE LITTON



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3.2 ENLRG

This task produces a times two enlargement of a digital image. The maximum input window of 258 x 258 pixels will yield an output image of 512 x 512. Rather than using a simple pixel repeat, ENLRG incorporates a sampling technique to generate four pixels for each input pixel. The algorithm utilizes the four nearest neighbors as follows:

$$GN1 = G3 + (G1 + G2 - G4 - G5)/8$$

$$GN2 = G3 + (G1 + G4 - G2 - G5)/8$$

$$GN3 = G3 + (G2 + G5 - G1 - G4)/8$$

$$GN4 = G3 + (G4 + G5 - G1 - G2)/8$$

Prior to generating the four new pixels the original gray values are stretched by the maximum allowable amount to minimize truncation in the calculations.

3.2.1 MAIN

The function of MAIN is to perform housekeeping tasks such as opening files and to provide a driver for the necessary subroutines. The image is scanned, a gray scale transformation is defined, and finally the image is enlarged.

3.2.1.1 Common Areas

a. LUN

1. LUNI - Input Image Logical Unit Number
2. LUNO - Output Image Logical Unit Number
3. NIN - Control Terminal Logical Unit Number
4. NOUT - Line printer Logical Unit Number

b. WINDIN

1. NROW - First row of input image
2. NROWS - Number of rows input
3. NCOL - First column of input image
4. NCOLS - Number of columns of input image

c. WINDOT

1. MROW - First row of output image
2. MROWS - Number of rows of output image
3. MCOL - First column of output image
4. MCOLS - Number of columns of output image

d. GRYSCL

1. Scale (256) - gray scale transformation vector

3.2.1.2 Variables

- a. HIST (256) - Histogram of scanned image
- b. INC - Scan increment
- c. NSKIP - Number of records to skip to position input window

3.2.2 SCAN

Subroutine SCAN accepts a Logical Unit Number, window coordinates, and a scan increment (N), and returns an accumulated histogram of every Nth pixel in every Nth row. SCAN does not reposition the file to its starting point.

3.2.2.1 Argument List

- a. NROWS - Number of rows to be scanned
- b. NCOLS - Number of columns to be scanned
- c. NROW - Starting row number
- d. NCOL - Starting column number
- e. HIST - (256) - Histogram counters

3.2.2.2 Common Areas

- a. LUN - See 3.2.1.1

3.2.2.3 Variables

- a. PIXEL - extracted gray value

3.2.3 HISTR

Subroutine HISTR accepts an image histogram and returns a gray scale transformation vector. First the minimum and maximum histogram limits are determined. The minimum is defined as that gray value for which there is a population of 25 which is either less than or equal to the gray value. The maximum is similarly defined so as to reduce the effect of high and low-level noise on the stretching process. Using these limits, a linear transformation is defined to stretch the maximum-minimum range the largest integer amount possible while remaining within the 0-255 limits.

3.2.3.1 Argument List

- a. HIST (256) - Accumulated histogram
- b. SCALE (256) - Gray scale transformation vector

3.2.3.2 Common Areas

None

3.2.3.3 Variables

- a. ICUT - minimum and maximum cutoff population
- b. MIN - minimum histogram value
- c. MAX - maximum histogram value
- d. MR - histogram range
- e. MA - maximum stretch value
- f. NMIN - new minimum value
- g. NMAX - new maximum value

3.2.4 EXPAND

Subroutine EXPAND reads the input image and produces an enlarged output image. It starts by initializing buffer pointers and reading the first few records of the image. After each record is written it is expanded to one pixel per full word and the transformation defined in HISTR is applied. A loop is entered in which the buffer point which indicates the order in which the buffers were filled are rotated, a record is read, expanded into the third buffer, and the enlargement is performed. Finally two records of the enlarged image are written and the loop restarts until the entire image has been enlarged.

3.2.4.1 Argument List

None

3.2.4.2 Common Areas

- a. WINDIN - See 3.2.1.1
- b. LIM
 - 1. LIM1 - first word in input window
 - 2. LIM2 - last word in input window
- c. LUN - see 3.2.1.1
- d. WINDOT - see 3.2.1.1
- e. DBUF
 - 1. BUFF1 (256) - input buffer and output buffer number 1
 - 2. BUFF2 (256) - output buffer number 2
- f. WBUF
 - 1. LINE (258,3) - three buffers for expanded data

3.2.4.3 Variables

- a. L1 - buffer pointer number 1
- b. L2 - buffer pointer number 2
- c. L3 - buffer pointer number 3
- d. BLEN2 - input buffer length
- e. BUFLN2 - output buffer length
- f. FLAG - end-of-file indicator
- g. INDEX - output buffer position pointer
- h. G1 - input gray value number 1
- i. G2 - input gray value number 2

- j. G3 - input gray value number 3
- k. G4 - input gray value number 4
- l. G5 - input gray value number 5

3.2.5 XPDBYT

Subroutine XPDBYT accepts a buffer of input data in the form of one pixel per byte, a transformation vector, and column limits. It returns a buffer of transformed gray values in the form of one pixel per word.

3.2.5.1 Argument List

- a. NUM - Buffer number to receive expanded data

3.2.5.2 Common Areas

- a. LIM - see 3.2.4.2
- b. GRYSCL - see 3.2.1.1
- c. DBUF - see 3.2.4.2
- d. WBUF - see 3.2.4.2

3.2.5.3 Variables

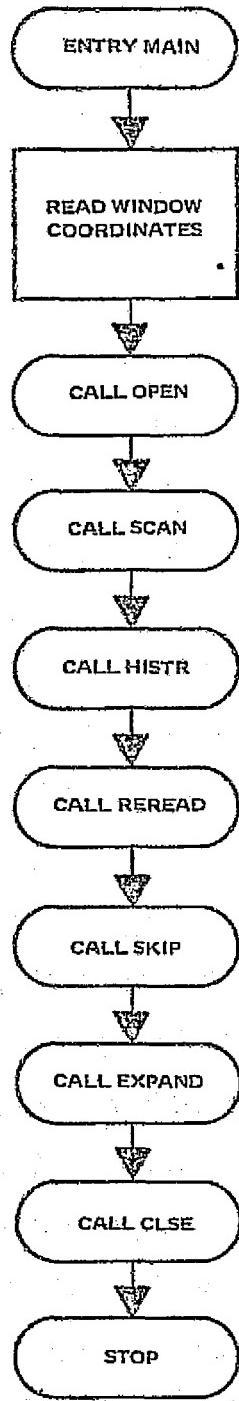
- a. HBYT - high order pixel
- b. LBYT - low order pixel

3.2.6 User's Guide

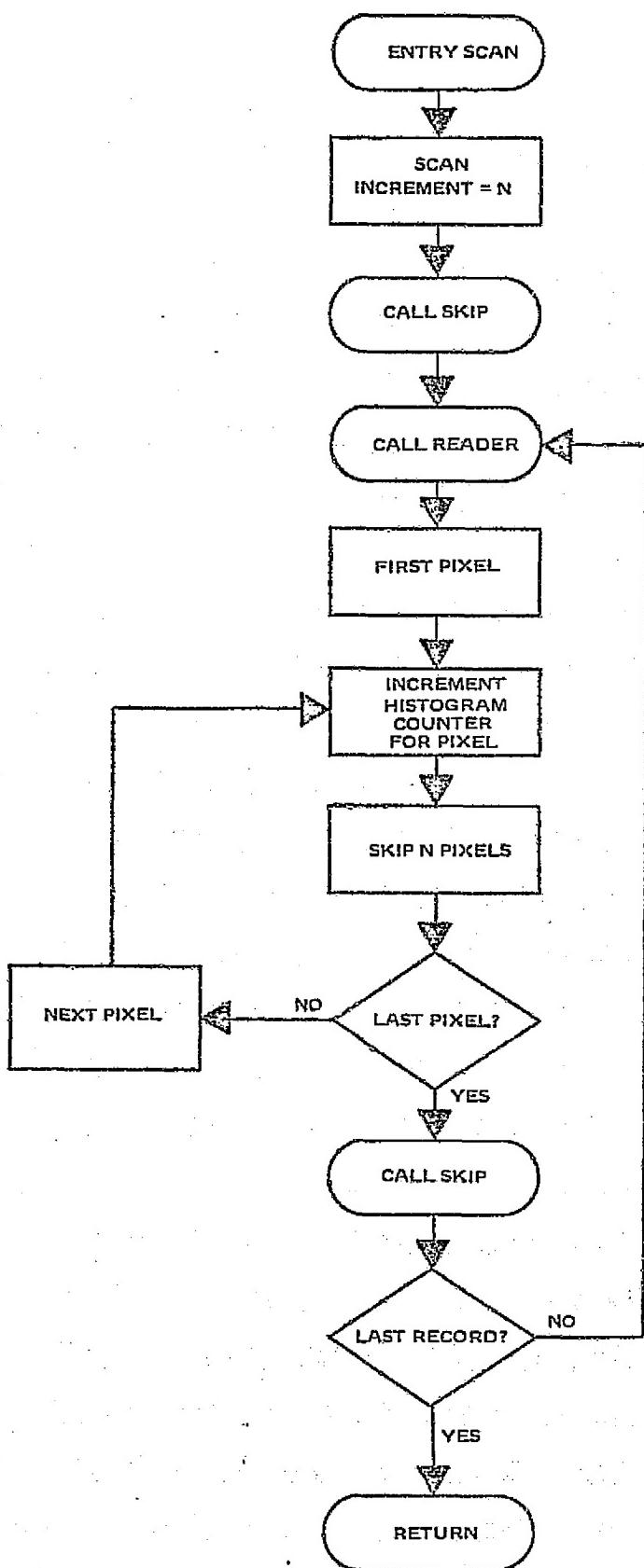
ENLRG is initiated by the MCR command RUN ENLRG\$. In addition to the information required by OPEN (see 2.1.4), the user will be prompted for the following:

| <u>PROMPT</u> | <u>RESPONSE</u> |
|---------------------|---------------------|
| START ROW = | Integer number |
| NUMBER OF ROWS = | Integer number |
| START COLUMN = | Odd integer number |
| NUMBER OF COLUMNS = | Even integer number |

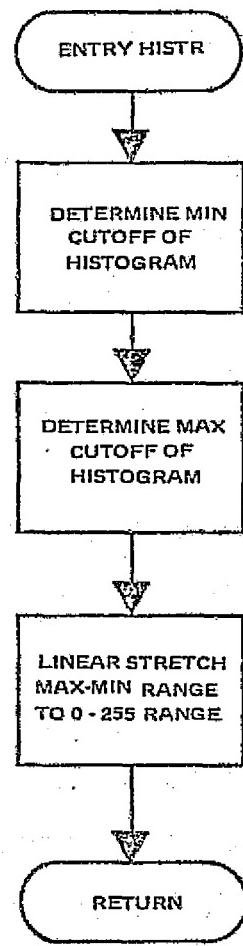
ENLARGE

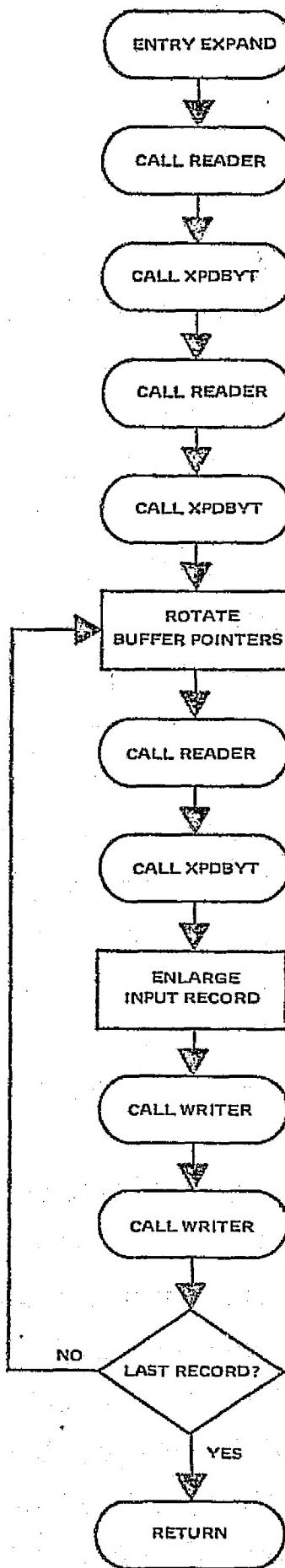


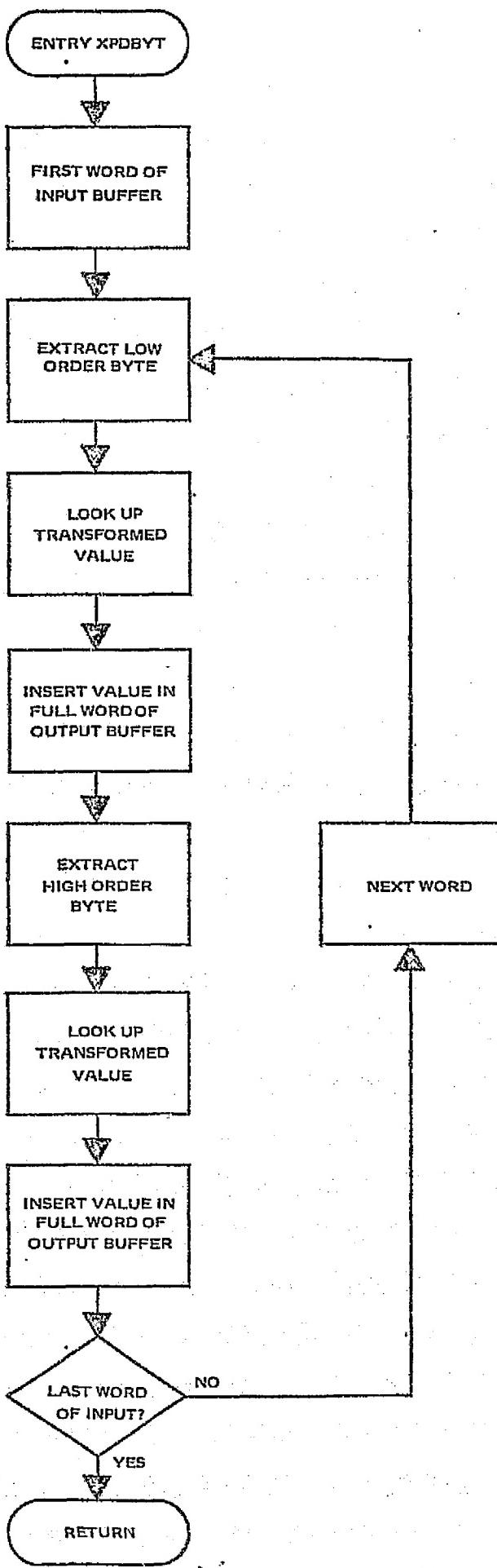
SCAN



HISTR







3.3 REDUCE

REDUCE produces a times two reduction of a digital image by replacing successive 2 x 2 pixel areas with their average gray value.

Before reduction takes place the image is scanned to determine the gray value range and a linear transformation is defined to provide the maximum amount of stretch without exceeding the gray value limit of 255.

The 2 x 2 averages are then calculated using the transform gray values thereby reducing integer truncation to a minimum.

3.3.1 MAIN

The function of MAIN is to perform housekeeping functions such as opening files, and to provide a driver for the necessary subroutines. The image is scanned, a gray scale transformation is defined, and finally the image is reduced.

3.3.1.1 Common Areas

a. WINDIN

1. NROW - First row input image
2. NROWS - Number of rows of input image
3. NCOL - First column of input image
4. NCOLS - Number of columns of input image

b. WINDOT

1. MROW - First row of output image
2. MROWS - Number of rows of output image
3. MCOL - First column of output image
4. MCOLS - Number of columns of output image

c. LUN

1. LUNI - Input image Logical Unit Number
2. LUNO - Output image Logical Unit Number
3. NIN - Logical Unit Number for control terminal
4. NOUT - Logical Unit Number for line printer

d. GRYSCL

1. SCALE (256) - gray scale transformation vector

3.3.1.2 Variables

- a. HIST (256) - Histogram of scanned image
- b. INC - scan increment
- c. NSKIP - number of rows to be skipped

3.3.2 SCAN

See 3.2.2

3.3.3 HISTR

See 3.2.3

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3.3.4 REDUCE

Subroutine REDUCE does the actual image reduction, generating one, half-length line for each two full-length lines of input. After each input line is read it is immediately expanded to one pixel per word in XPDBYT. The reduction process consists of an arithmetic average over a 2 x 2 pixel area rather than a simple sampling technique.

3.3.4.2 Argument List

None

3.3.4.3 Common Areas

- a. LUN - see 3.3.1.1
- b. LIM
 - 1. LIM1 - first word of input buffer
 - 2. LIM2 - last word of input buffer
- c. WINDIN - see 3.3.1.1
- d. WINDOT - see 3.3.1.1

3.3.4.4 Variables

- a. BUFF1 (256) - first input buffer
- b. BUFF2 (256) - second input buffer also used as output buffer
- c. LINE (2,1024) - buffer area for expanded lines
- d. BLEN - input buffer length
- e. BLEN2 - output buffer length (words)
- f. FLAG - end-of-file flag
- g. GN1 - contains first of pair of generated pixels
- h. GN2 - contains second of pair of generated pixels

3.3.5 XPDBYT

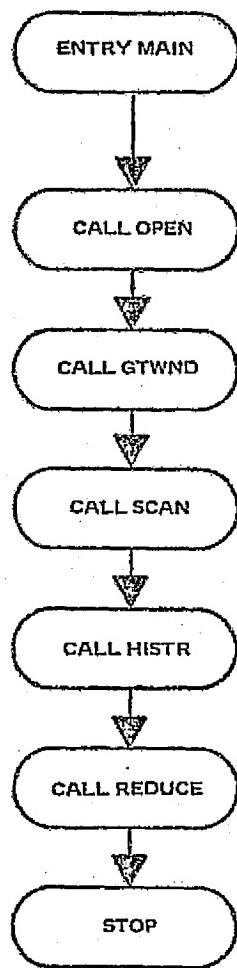
See 3.2.5

3.3.6 User's Guide

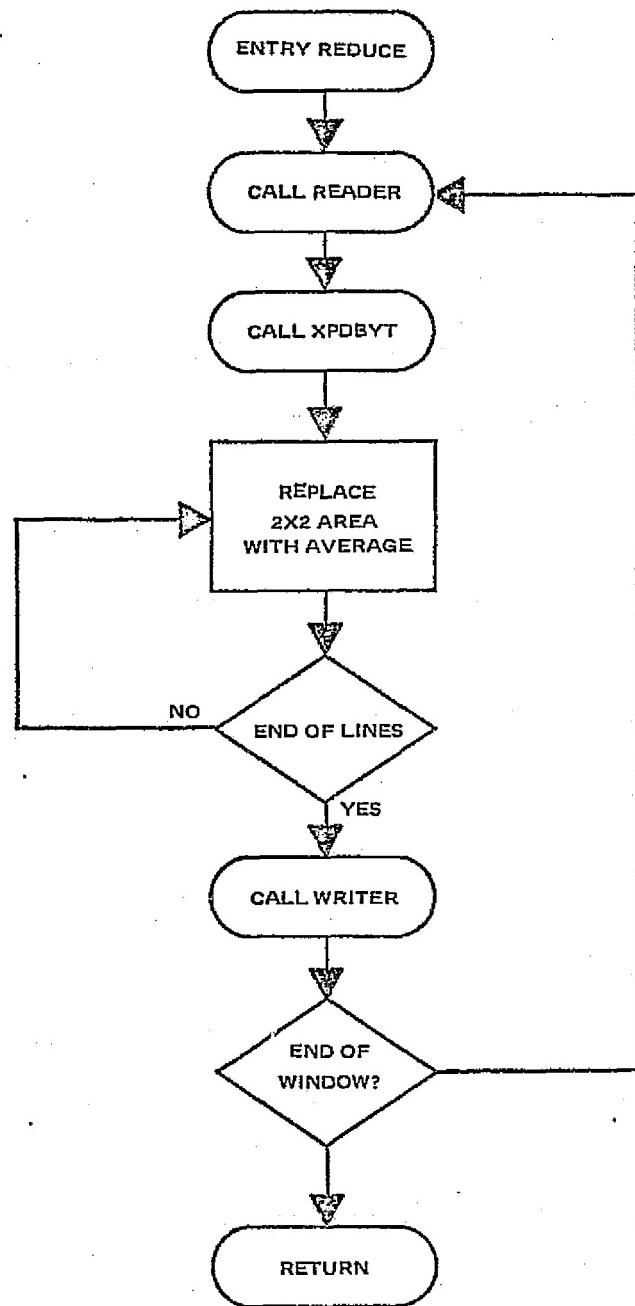
REDUCE is initiated by the MCR command RUN REDUCE\$. In addition to the information required by OPEN (see 2.1.4), the user will be prompted for the following information:

| <u>PROMPT</u> | <u>RESPONSE</u> |
|-------------------------|---------------------|
| INPUT PARAMETERS | |
| START ROW = | Integer number |
| NUMBER OF ROWS = | Integer number |
| START COLUMN = | Odd integer number |
| NUMBER OF COLUMNS = | Even integer number |

REDUCE



REDUCE



3.4 PSPECT

PSPECT is designed to produce a 2-D projection of a 3-D surface. Output is directed to a sequential devide or the TEKTRONIX graphics terminal depending on which version is used (11/70 or IMAGE-100). The surface to be displayed is defined by a 50 x 50 array of floating point words. The line of view of the output image is the 45° diagonal running from row 50, column 1 to row 1, column 50. The surface is also elevated along the line of view at an angle of 60°.

3.4.1 MAIN

First the input image is read into a 50 x 50 integer array. The image is then tilted upward at a 60° angle and projected onto a vertical plane. The projected height is scaled upward by a factor of 10, and this scaled value is entered into a 50 x 50 array of floating point numbers. When completed this array contains the output buffer position of each node in the image.

After projecting the input image the output image is generated by interpolating between nodes to obtain intermediate points. Processing is done by diagonal starting with the upper left diagonal. Each diagonal is processed one node at a time starting at the lower left.

For each diagonal the number of nodes is calculated using the FUNCTION NNODE. For each node in the diagonal slopes are calculated to the two nearest neighbor nodes in the next diagonal. These slopes are then used to define the connecting links between nodes. Nine lines of output are generated between diagonals to display these links. As processing continues up each diagonal a

maximum height value is saved which defines the hidden point criterium. In constructing the output buffer if a point is encountered which is lower than the current maximum for the diagonal this point is ignored as a hidden point.

3.4.1.2 Common Areas

a. DATAB

1. ARRAY (50,50) - integer array of image data before projection

3.4.1.3 Variables

- a. MAT (50,50) - REAL*4, image data after projection
- b. SLOPE (3,50) - REAL*4, slope information for each node in diagonal
- c. KEY (2) - REAL*4, slope information for one node
- d. ROW - REAL*4, row number in input image
- e. COL - REAL*4, column number in input image
- f. BUFF (1536) - output buffer
- g. NDIAG - number of diagonals in image
- h. NODE - number of nodes in diagonal
- i. I1 - row position of node
- j. J1 - column position of node
- k. NO - number of adjacent nodes
- l. MAX - maximum value in diagonal

3.4.2 NNODE

NNODE is an integer FUNCTION which returns the number of nodes in a given diagonal of a square matrix.

3.4.2.1 Argument List

- a. N - order of matrix
- b. NO - diagonal number

3.4.3 CONECT

Subroutine CONECT accepts a matrix order, diagonal number, node number, and an input image. It returns the number of nodes adjacent to the input node and the slope between the input node and each adjacent node.

3.4.3.1 Argument List

- a. N - order of matrix
- b. IDN - diagonal number
- c. NO - node number
- d. A(50,50) - REAL*4, projected image
- e. SLOPE (2) - slope to each adjacent node
- f. NC - number of adjacent nodes (0-2)

3.4.3.2 Variables

- a. IS - row number of node
- b. JS - column number of node
- c. I1 - row number of first adjacent node
- d. J1 - column number of first adjacent node

- e. I2 - row number of second adjacent node
- f. J2 - column number of second adjacent node

3.4.4 DETIJ

Subroutine DETIJ accepts a diagonal number, node number, and matrix order and returns the row and column number of the node.

3.4.4.1 Argument List

- a. I - row number of node
- b. J - column number of node
- c. ND - number of diagonal
- d. K - number of node
- e. N - square size

3.4.5 IN21

IN21 is an I/O routine which reads one line of image data and expands that data so that each pixel occupies a full (2 byte) word of storage.

3.4.5.1 Argument List

- a. BUFF1 (512) - buffer for expanded data

3.4.5.2 Common Areas

None

3.4.5.3 Variables

- a. BUFF2 (256) - buffer for original data
- b. LUN - Logical Unit Number

3.4.6 OUT22

OUT22 accepts a buffer of image data in the form of one pixel per full word, compresses the data to one pixel per byte and writes the compressed data to the output file.

3.4.6.1 Argument List

- a. BUFF (1536) - Data buffer

3.4.6.2 Common Areas

None

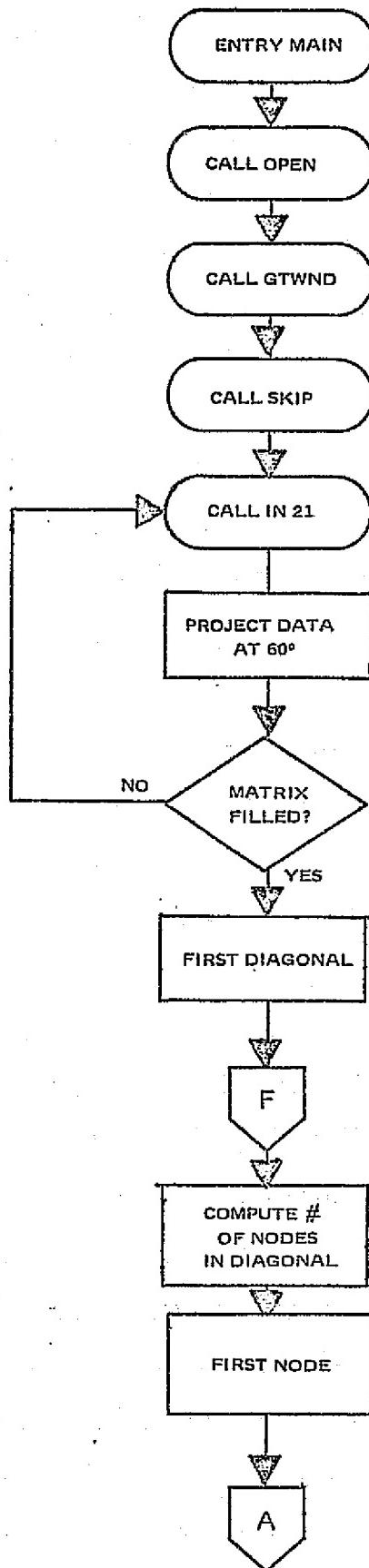
3.4.6.3 Variables

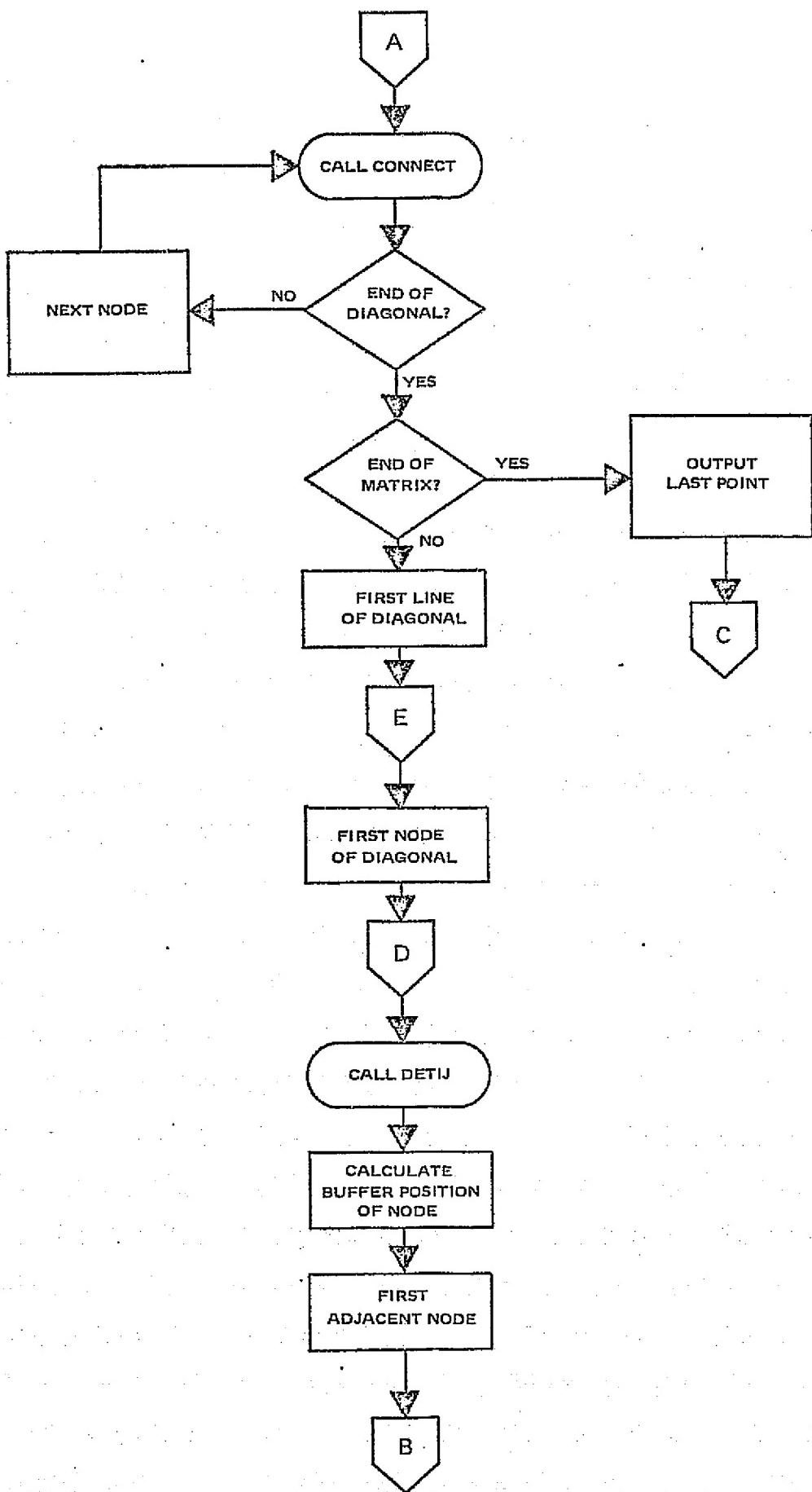
- a. LBYT - low order byte of compressed word
- b. HBYT - high order byte of compressed word

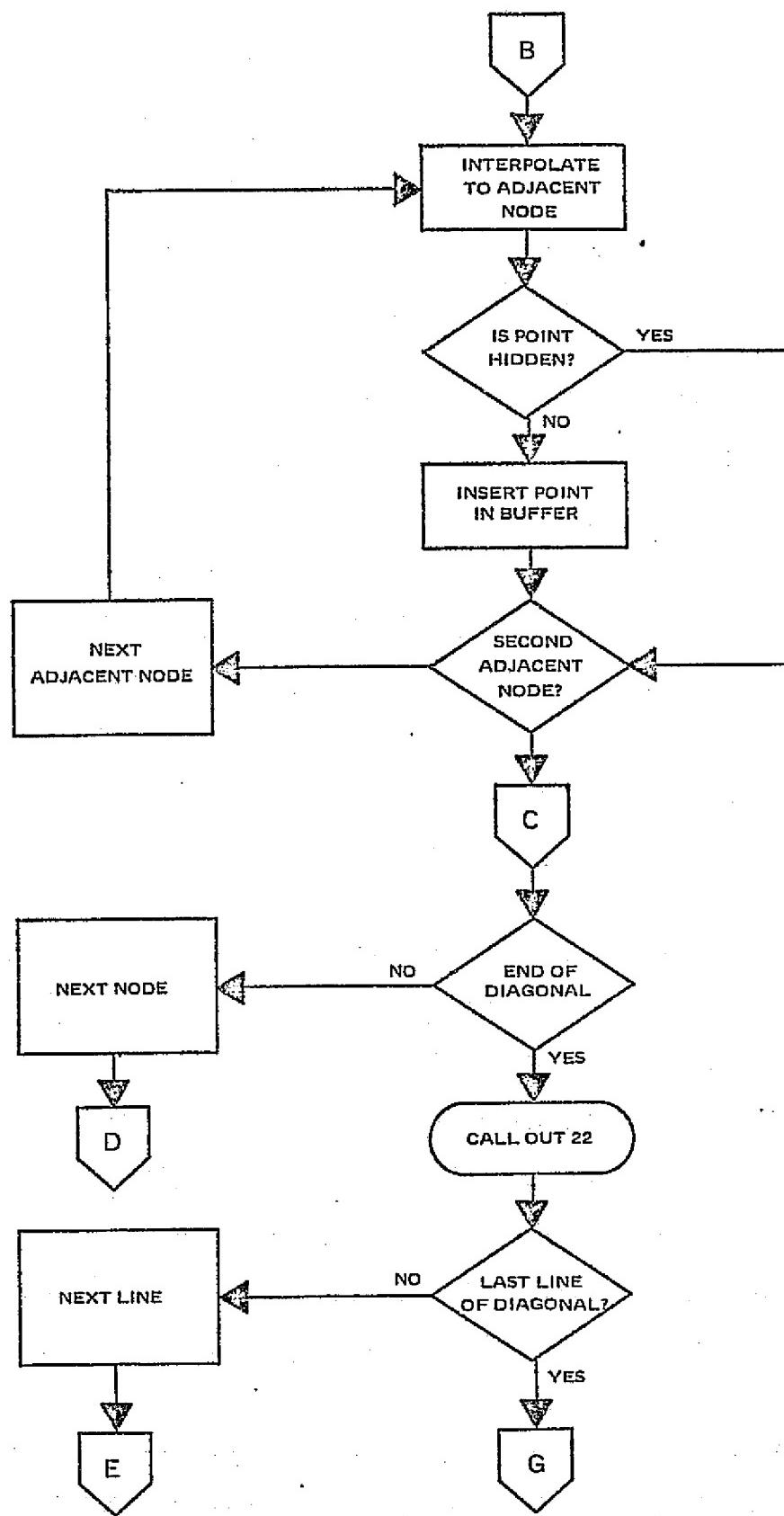
3.4.7 User's Guide

PSPECT is initiated by MCR command RUN PSPECT\$. All user-supplied information is requested in OPEN (see 2.1.4) and GTWND (see 2.16.4).

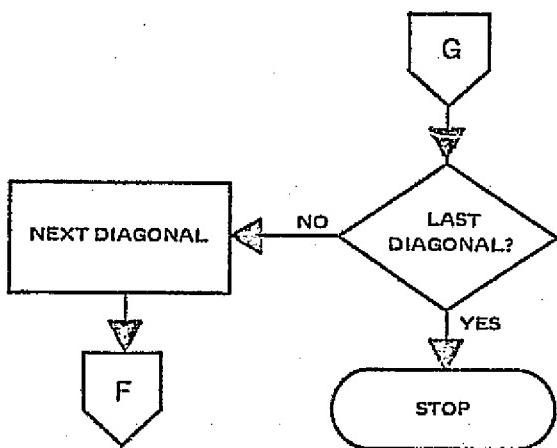
PSPECT



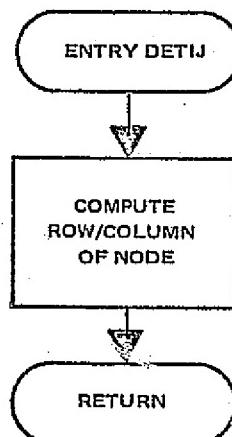




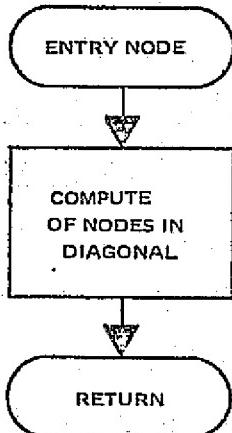
PSPECT



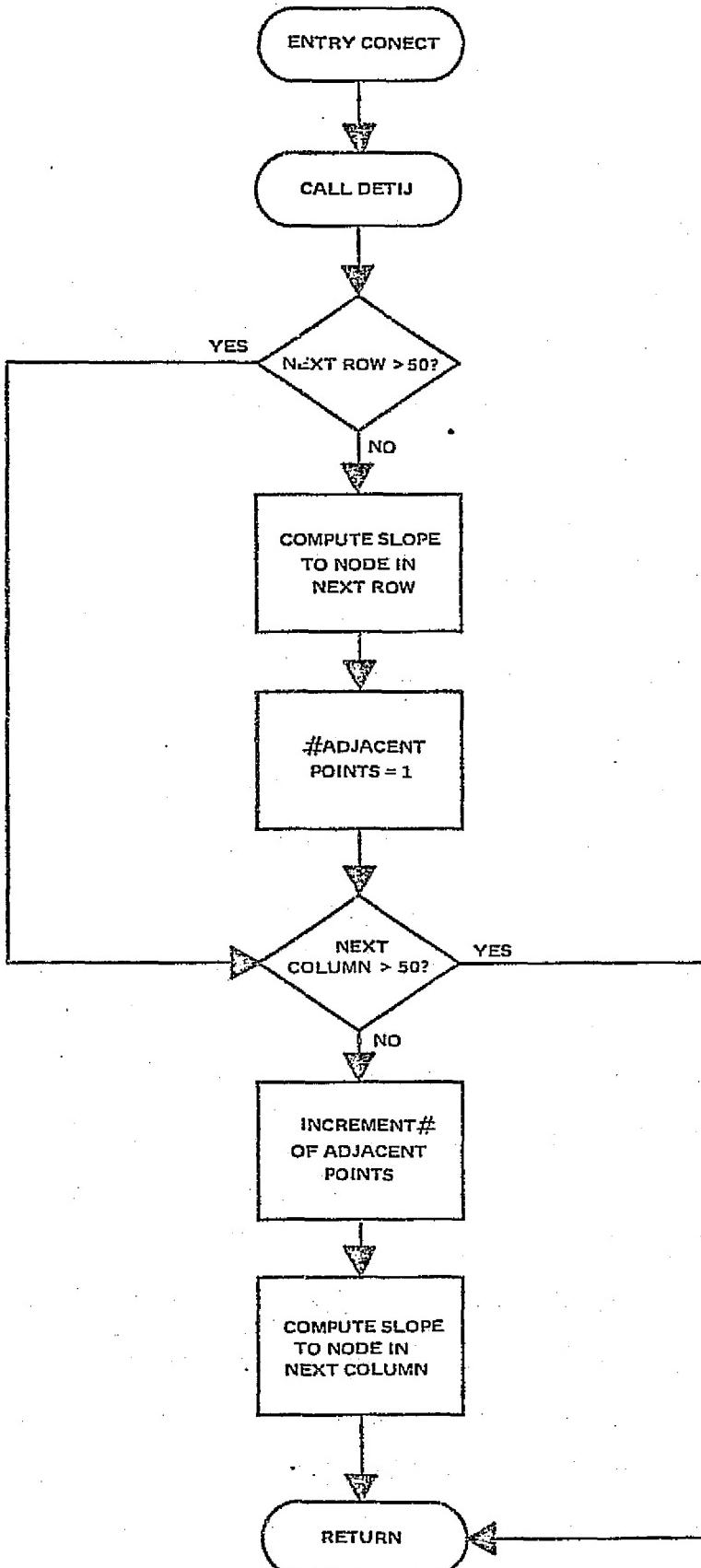
DETIJ



NNODE

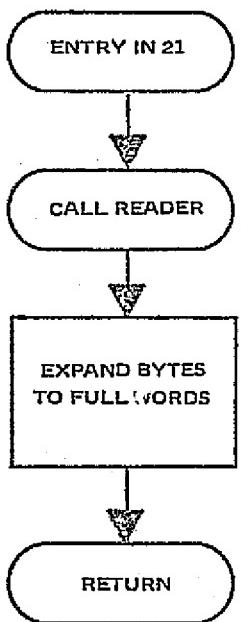


CONECT

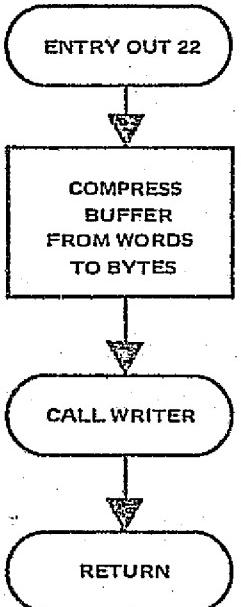


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IN 21



OUT 22



3.5 INTERP

Subroutine INTERP interpolates point source data from up to six sources and returns a weighted value for a point which is a specified distance from each source. Weighting is done by an inverse distance equation.

3.5.1 Argument List

- a. XN (6) - REAL*4, input data from 6 sources
- b. XMULT (6) - REAL*4, distance from each source to desired point
- c. VALUE - REAL*4, weighted value

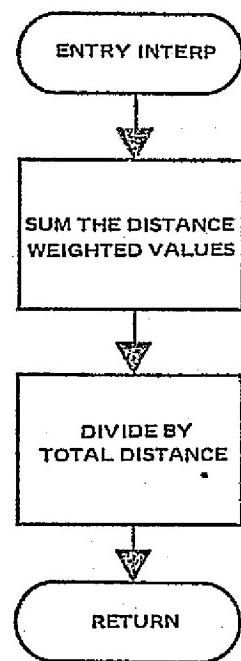
3.5.2 Common Areas

None

3.5.3 Variables

- a. DEN - REAL*4, sum of distances

INTERP



3.6 BSTBND

Program BSTBND (Best band) allows the user to perform an eigenvalue analysis of an image. The user is prompted to identify an image window on the screen of the Image 100 with the cursor. Subroutine COVAR calculates the four band mean vector and full variance/covariance matrix for the image window. Subroutine GETEIG uses the means and variance/covariance matrix in an eigenvalue analysis. Subroutine GETEIG prints out and returns to the main program the eigenvalues and the corresponding orthonormal eigenvectors for the specific variance/covariance matrix. The user is then prompted to select a particular eigenvector to project the image on. Subroutine COMBIN performs the actual image projection. A new image is generated which corresponds to the 4D image projected onto a 1D plane in the direction of the selected eigenvector.

3.6.1 MAIN

Entry point MAIN is a main driver for program BSTBND. The processing sequence controlled by MAIN is;

1. Open I/O files,
2. Select image window,
3. Calculate variance/covariance
4. Perform eigenvalue analysis,
5. Select eigenvector on which to project image,
6. Project image onto vector
7. Repeat steps 5 and 6.

3.6.1.1 Common Areas

None.

3.6.1.2 Variables

- a. MEAN (4) - REAL*4 - Vector of means
- b. VAR (10) - REAL*4 - Variance matrix stored in symmetric form
- c. EIBEN (4) - REAL*4 - Vector of eigenvalues
- d. EVEC (4,4) - REAL*4 - Vector of eigenvectors
- e. VEC (4) - REAL*4 - Work vector

3.6.2 COVAR

Subroutine COVAR allows the user to select a window of the image displayed on the screen of the Image 100. The subroutine then accesses the window and calculates the variance/covariance matrix of that window. The 4D mean vector, variance/covariance matrix, and the number of pixels in the window are returned to the calling program.

3.6.2.1 Argument List

- a. MEAN (4) - REAL*4 - Mean vector
- b. VAR(10) - REAL*4 - Variance/covariance matrix
- c. NUM - INTEGER*2 - Number of pixels

3.6.2.2 Common Areas

a. DBUF

- 1. BUF1 (256) - INTEGER*2 - Data buffer
- 2. BUF2 (256) - INTEGER*2 - Data buffer
- 3. BUF3 (256) - INTEGER*2 - Data buffer
- 4. BUF4 (256) - INTEGER*2 - Data buffer

3.6.2.3 Variables

- a. BUFF (256,4) - INTEGER*2 - Data area equivalent to BUF1-BUF4.
- b. SUM (4) - INTEGER*4 - Intermediate storage of means
- c. SUM2 (10) - REAL*4 - Intermediate storage of variance matrix
- d. PIX1 (4) - INTEGER*2 - Intermediate storage for gray values
- e. PIX2 (4) - INTEGER*2 - Intermediate storage for gray values
- f. PI (4) - REAL*4 - Intermediate storage for gray values
- g. P2 (4) - REAL*4 - Intermediate storage for gray values.

3.6.3 GETEIG

Subroutine GETEIG acts as an interface between the main program and the eigenvalue analysis routine. Subroutine GETEIG begins by transferring the variance matrix to a work array. Subroutine EIGEN is called to calculate the eigenvalues and eigenvectors. Subroutine LOCATE is used to decode the storage mode of the eigenvalues and eigenvectors. The original variance matrix is printed out along with the eigenvalues and eigenvectors.

3.6.3.1 Argument List

- a. NV - INTEGER*2 - Order of matrix (default of 4)
- b. VAR (10) - REAL*4 - Variance matrix

- c. EIGVAL (4) - REAL*4 - Eigenvalues
- d. EIGVEC (4,4) - REAL*4 - Eigenvectors

3.6.3.2 Common Areas

None.

3.6.3.3 Variables

- a. WVAR (10) - REAL*4 - Work vector
- b. WVEC (16) - REAL*4 - Work vector
- c. LINE (4) - REAL*4 - Work vector

3.6.4 EIGEN

Subroutine EIGEN computes the eigenvalues and eigenvectors of a real symmetric matrix. Subroutine EIGEN is an adapted version of an IBM Scientific Subroutine Package (SSP).

3.6.4.1 Argument List

- a. A (10) - REAL*4 - Original matrix in symmetric form, destroyed in computation
- b. R (16) - REAL*4 - Resultant matrix of eigenvectors
- c. N - INTEGER*2 - Order of matrix A
- d. MV - INTEGER*2 - Input code, 0 to compute both eigenvalues and eigenvectors, 1 to compute only eigenvalues.

3.6.4.2 Common Areas

None.

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3.6.4.3 Variables

None.

3.6.5 LOC

Subroutine LOC is an IBM utility subprogram used by the Scientific Subroutine Package. The function of the routine LOC is to allow for easy conversion from one storage mode to another by computing a vector subscript for an element of a matrix.

3.6.5.1 Argument List

- a. I - INTEGER*2 - Row number
- b. J - INTEGER*2 - Column number
- c. IR - INTEGER*2 - Vector subscript
- d. N - INTEGER*2 - Number of rows in matrix
- e. M - INTEGER*2 - Number of columns in matrix
- f. MS - INTEGER*2 - Storage mode of matrix
 - 0 - General
 - 1 - Symmetric
 - 2 - Diagonal

3.6.5.2 Common Areas

None.

3.6.5.3 Variables

None.

3.6.6 COMBIN

Subroutine COMBIN is a general routine which allows calculation of a new image by forming a linear combination of four input images. The subprogram scans the input images forming the specific linear combination to identify an output maximum and minimum. The image is then generated and scaled accordingly.

3.6.6.1 Argument List

- a. COEFF (4) - REAL*4 - Vector of coefficients defining the linear combination

3.6.6.2 Common Areas

- a. DBUF - See section 3.6.2.2

3.6.6.3 Variables

- a. PIXEL - REAL*4 - Resultant gray value
- b. MAX - REAL*4 - Calculated image maximum
- c. MIN - REAL*4 - Calculated image minimum
- d. GAIN - REAL*4 - Resultant gain for scaling
- e. BUFF (256,4) - See section 3.6.2.3

3.6.7 User's Guide

BSTBND is initiated by the MCR command RUN BSTBND\$. In addition to the inputs required by GTWND (See section 2.16), the user would be prompted for the following:

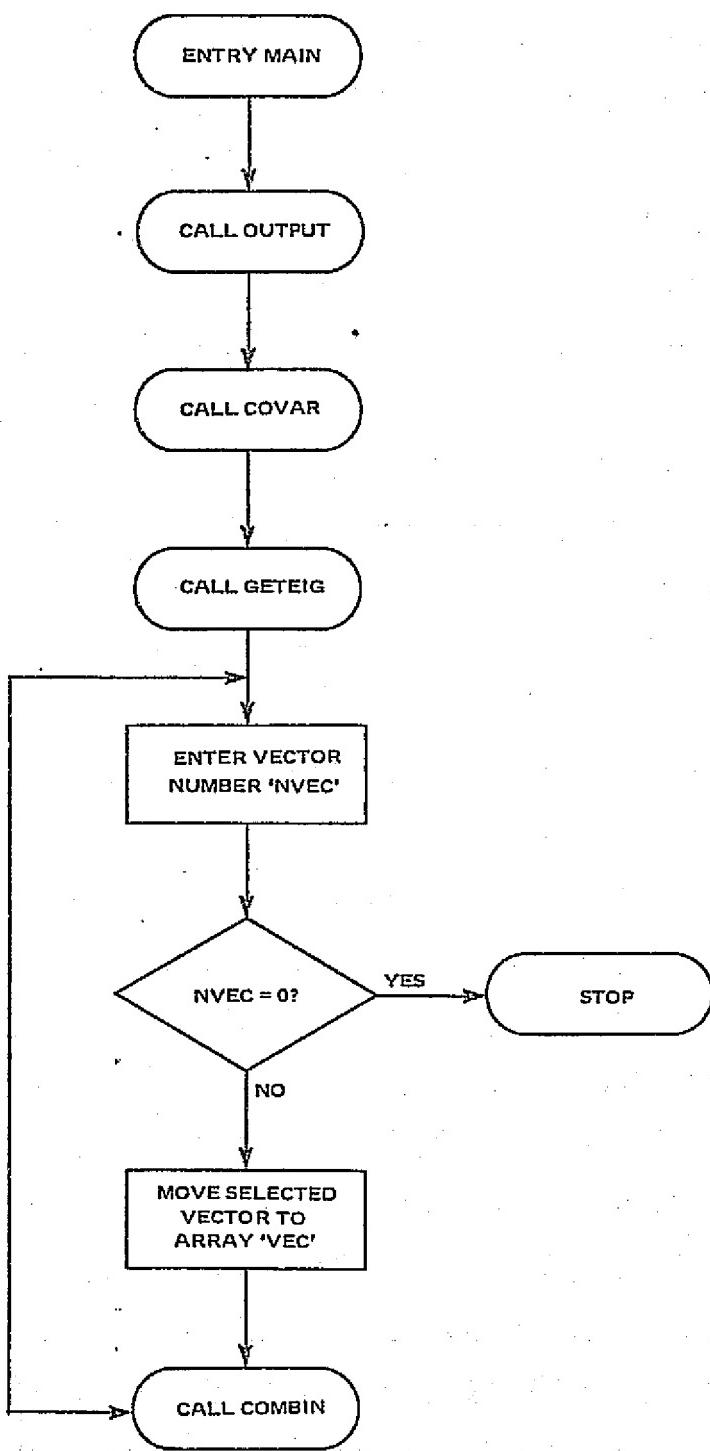
PROMPT

VECTOR NUMBER ?

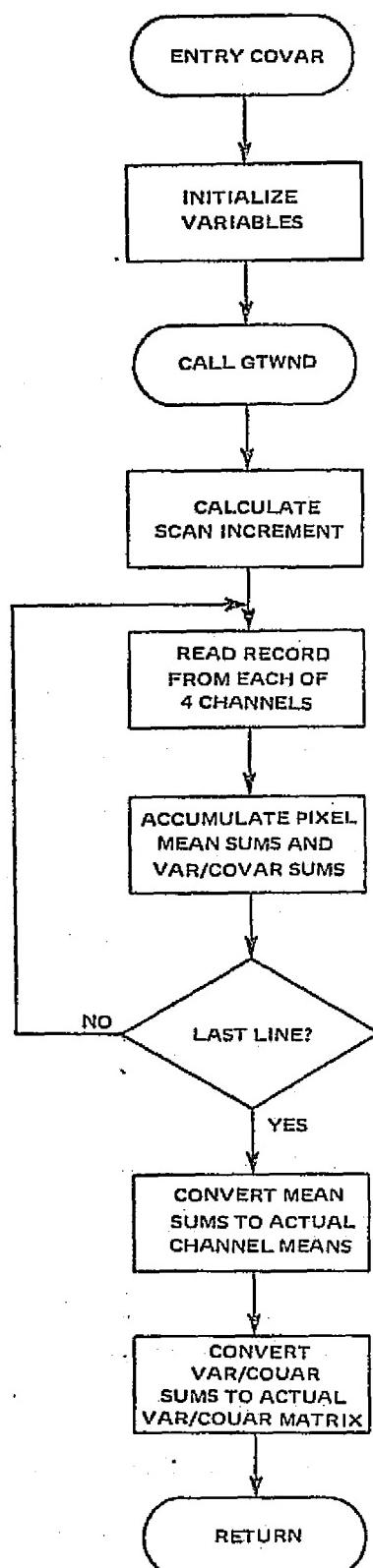
RESPONSE

Integer between 0 and 4

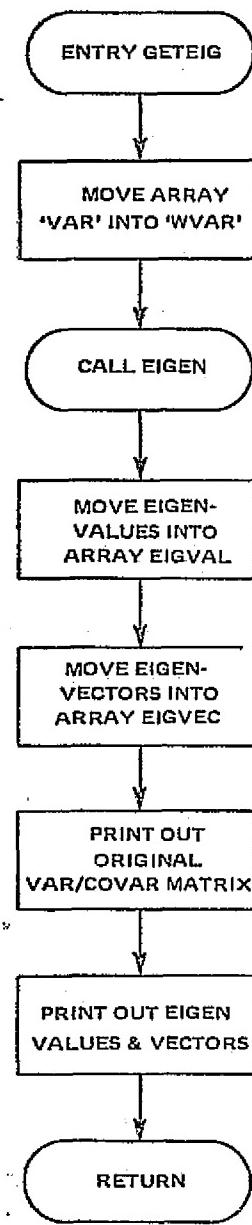
BSTBND



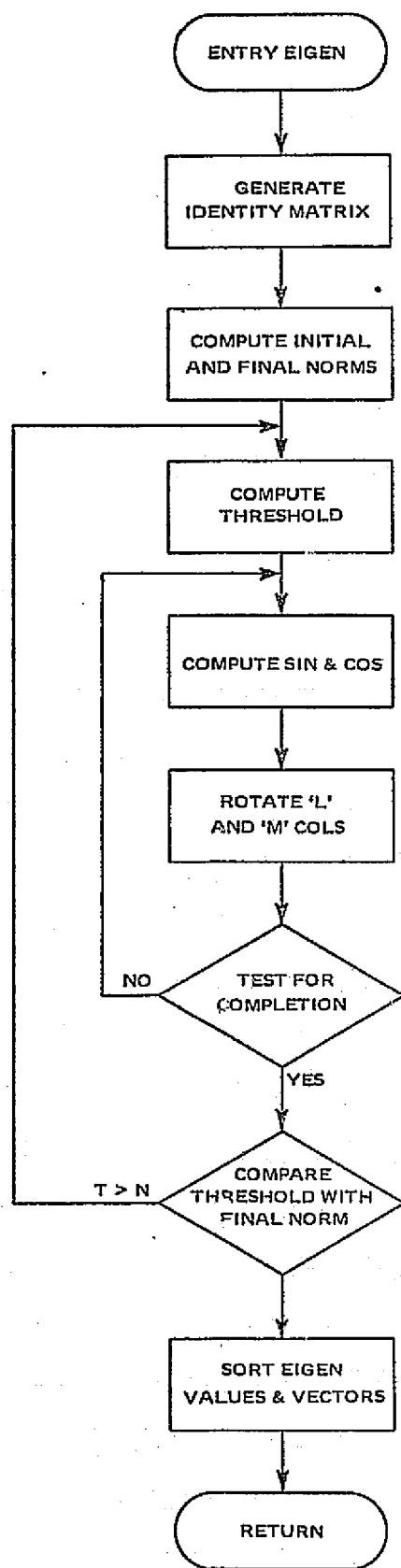
COVAR



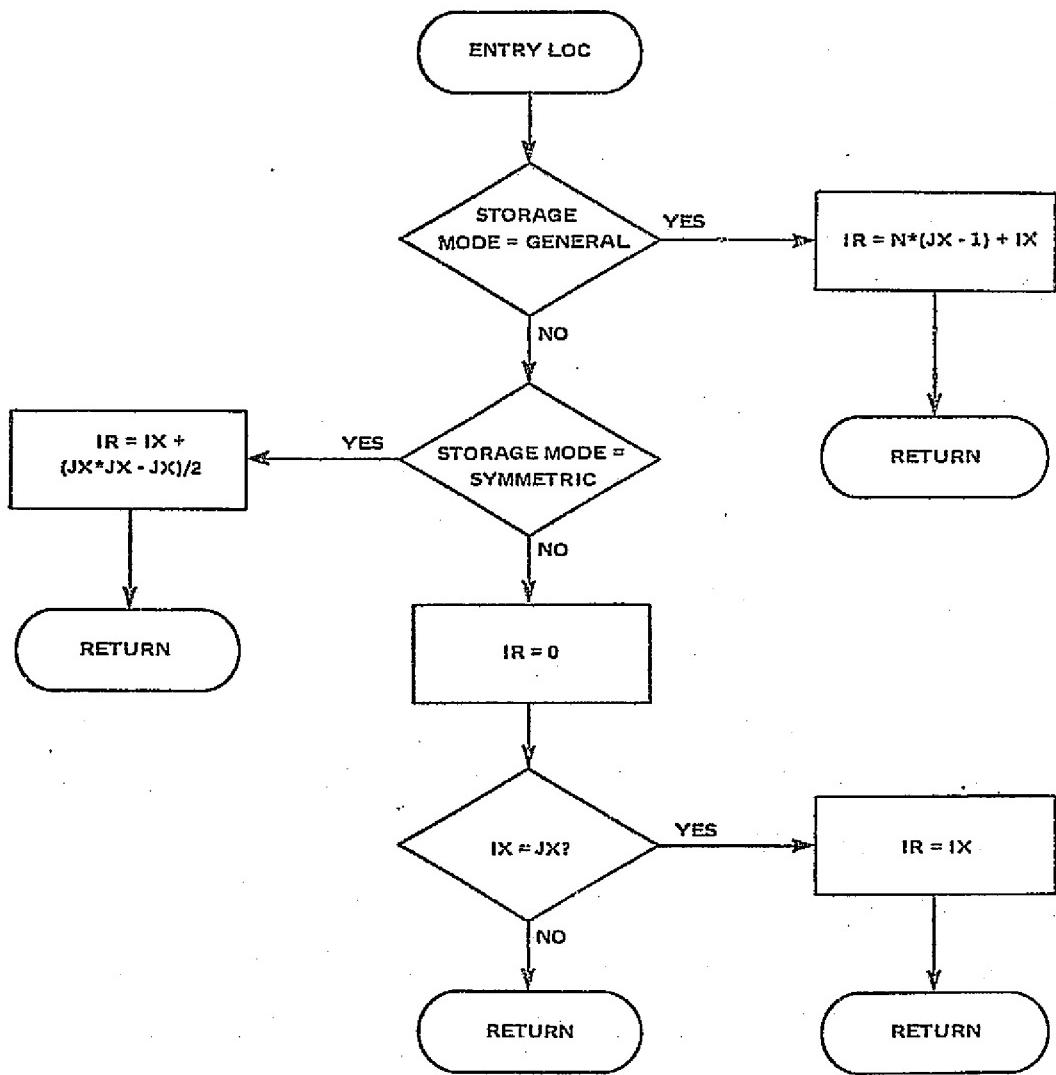
GETEIG



EIGEN

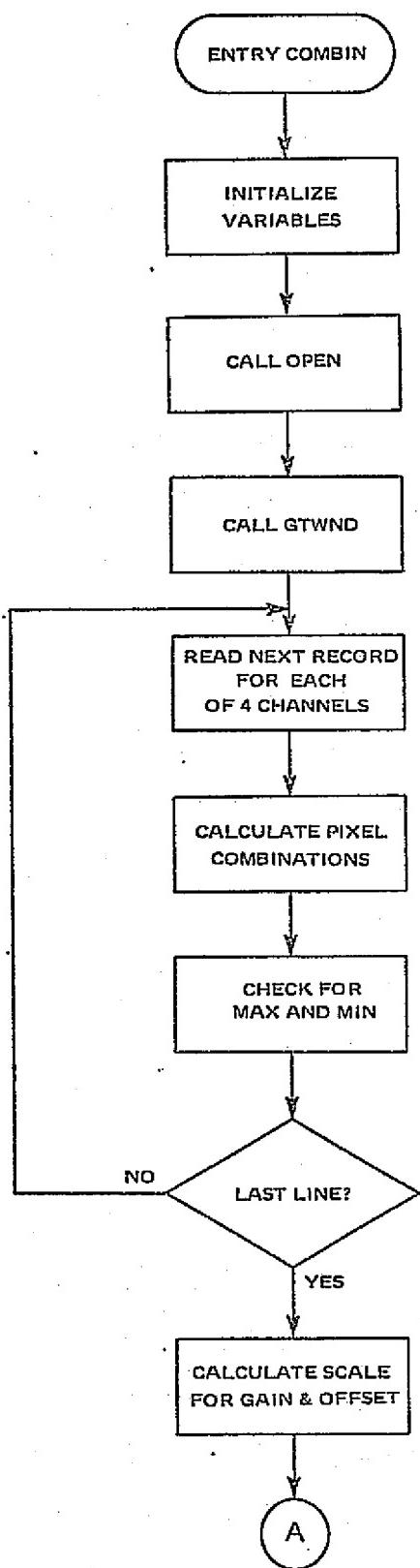


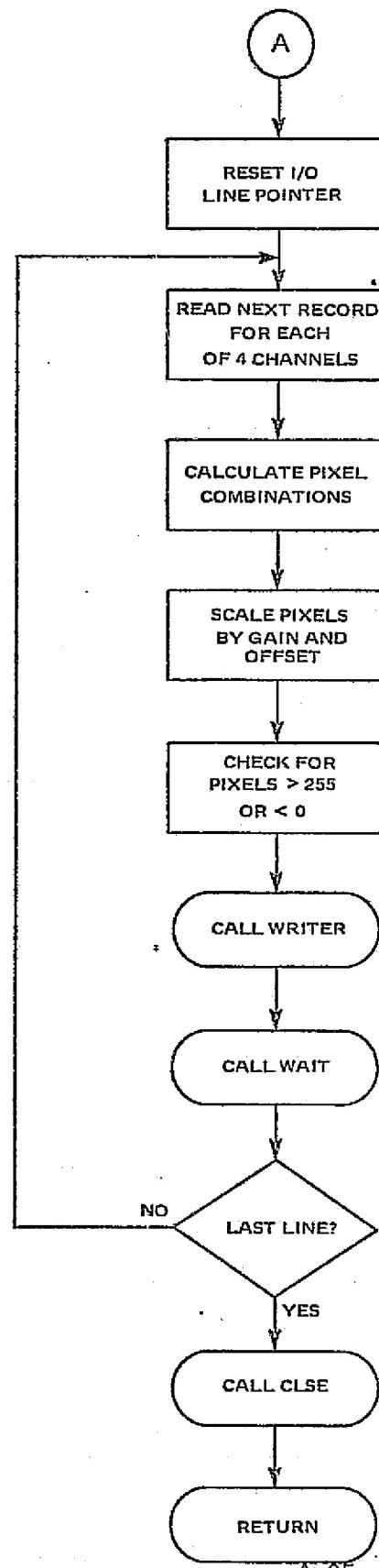
LOC



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COMBIN





3.7 GRID

See 4.9.3

3.8 POLYGO

POLYGO allows the user to produce a binary polygon map on any one of the theme planes on the IMAGE-100. Up to 20 polygon vertices may be indicated using the IMAGE-100 cursor. POLYGO will then connect adjacent vertices and fill in all enclosed points.

3.8.1 MAIN

MAIN acts only as a driver for all of the subroutines which make up POLYGO. First, the output buffer (for writing to theme plane) is cleared. GETPNT is called to input the vertices, BORDER is called to connect them, and SORT is called to sort the border points by ascending row. Finally FILLIN is called to fill in all enclosed points and write them out to the desired theme. At this point, the user has the option of restarting or exiting.

3.8.1.1 Common Areas

a. VTX

1. POINT (2,1000,2) - Storage area for border points.
2. NPT - Number of points.
3. VERTEX (2,20) - Storage area for vertices.

4. NVTX ~ Number of vertices.
5. LINK (21) - Link pointers used for merge sorting.

b. DBUF

1. BUFF (32) - Output buffer to theme.

3.8.1.2 Variables

- a. N - Indicates position of sorted point list (1 or 2).

3.8.2 GETPNT

Subroutine GETPNT is an interface routine which allows the user to input vertices through the IMAGE-100 cursor. The system subroutine IRK is used to read the cursor; as each point is read it is placed in the array VERTEX. GETPNT will automatically exit after 20 points or the user may exit before 20 points by repeating the last one.

3.8.2.1 Argument List

None

3.8.2.2 Common Areas

- a. NTHM
 1. THEME - Theme for output (1-8).
- b. DBUF - See 3.8.1.1
- c. VTX - See 3.8.1.1

3.8.2.3 Variables

- a. X - Last X value
- b. Y - last Y value
- c. XDIF - current X minus last X
- d. YDIF - current Y minus last Y

3.8.3 BORDER

Subroutine BORDER accepts a list of polygon vertices in VERTEX and returns a list of border points in POINT. It also returns a list of link pointers (LINK) which indicate the position of each vertex in point. For each vertex the slope to the next vertex clockwise is calculated. The vertex and slope define an equation for a line into which known row values can be substituted to determine the column values of the border points. These points, generated in ascending row order for each side, result in a point list which is locally sorted by row. The link pointers indicate the limits of these sorted regions.

3.8.3.1 Argument List

None

3.8.3.2 Common Areas

- a. VTX - See 3.8.1.1

3.8.3.3 Variables

- a. SLOPE - REAL*4, slope between adjacent vertices.
- b. XREAL - REAL*4, computed column value.
- c. X1 - Column value of vertex with lower row number.

- d. Y1 - Row value of vertex with lower row number.
- e. X2 - Column value of vertex with higher row number.
- f. Y2 - Row value of vertex with higher row number.

3.8.4 SORT

Subroutine SORT accepts a locally sorted list of border points and a list of pointers indicating these local regions and returns a globally sorted list of border points. A merge sorting algorithm is used which requires two storage areas; hence, it is also necessary to return a flag which indicates in which area the sorted array resides.

A number of locally sorted groups is equal to the number of polygon vertices. Each adjacent pair is merged together by comparing row values of the two top points in placing the point with a lower row value into the new area. This process continues until one of the groups is depleted, at which point the remaining group is simply transferred to the new area. Each pair of groups is merged in this fashion. If there is an odd number of groups the last one is transferred with no merging. At the end of each pass the number of groups is halved (except in case of odd group), so that the total number of passes is $\log_2 N$ where N is the initial number of groups.

3.8.4.1 Argument List

- a. N2 - Array number (1 or 2) in which sorted list resides.

3.8.4.2 Common Areas

- a. VTX - See 3.8.1.1

3.8.4.3 Variables

- a. NGP - Number of groups in array.
- b. ODD - Indicate presence of odd number of groups.
- c. N1 - Old array number.
- d. I1 - Number of group 1 (points into LINK).
- e. I2 - Number of group 2 (points into LINK).
- f. P1 - Position pointer for group 1.
- g. P2 - Position pointer for group 2.
- h. INDX - Position pointer for new array.

3.8.5 FILLIN

Subroutine FILLIN accepts the sorted list from SORT, determines the interior polygon points, and calls insert to produce a binary map on the IMAGE-100 screen. Filling takes place one row at a time, left to right. Each row is first sorted by ascending columns before filling takes place. The filling algorithm can be broken into three general cases:

1. Only one point in row (must be a vertex)
2. Two or more points in row - no vertices.
3. Two or more points in row - one or more vertices.

Treatment of cases one and two are straightforward. In case one a single point is written on the screen. In case two points one and two, three and four, five and six, etc., are connected (when no vertices are present there must always be an even number in points).

In case three complications can arise when a vertex is encountered. This can be broken again into three subcases.

- 3A. The vertex is in a region which is monotonically increasing or decreasing.
- 3B. The vertex is a local maximum, or minimum.
- 3C. The vertex marks the transition from a positive or negative slope to a zero slope.

Case 3A requires that the vertex be treated as a normal border point. When a border point is encountered and the print switch is off, the point is saved as a print switch initiator and the print switch is turned on. When a border point is encountered and the print switch is on, the points between the previous point and the current point are filled after which the print switch is turned off. At the beginning of each new row the print switch is off.

Case 3B causes no change in the print switch. If the print switch is off, the vertex is output as a single point. If the print switch is on, the vertex is ignored because it will be filled when the next border point is encountered.

In case 3C a zero slope is encountered and the slope must remain zero until another vertex is encountered. Hence, the next point in the row must also be a vertex and filling must take place between these adjacent vertices. Therefore, if the print switch was initially on it is left on and the first vertex is ignored. If the print switch was off it is now turned on and the position of the first vertex is saved as the print switch initiator.

Now the second vertex is considered. This vertex has two adjacent vertices, one of which is the other half of the zero slope

pair. The adjacent vertex of interest is the one which is connected with a non-zero slope. At this point one of two courses is taken depending on the sign of the slope and the position of this adjacent vertex.

1. Turn off print switch fill between column where switch was initiated and second zero slope vertex.
2. Leave print switch on, go to next point. Course one is taken if either 1) the adjacent vertex is on clockwise side with the negative slope or 2) the adjacent vertex is on the counter clockwise side with a positive slope. Course two is taken if 1) the adjacent vertex is on the clockwise side with a positive slope or 2) the adjacent vertex is on the counter clockwise side with a negative slope. Filling continues until all rows have been processed; control is then returned to MAIN.

3.8.5.1 Argument List

- a. PT (2,1000) - Sorted list of border points.

3.8.5.2 Common Areas

- a. VTX - See 3.8.1.1
- b. DBUF - See 3.8.1.1
- c. NTHM - See 3.8.2.2

3.8.5.3 Variables

- a. VTXR (5) - Storage compositions of vertices in current row.
- b. INDEX - Position pointer in sorted array.

- c. NPR - Number of points in current row.
- d. NVR - Number of vertices in current row.
- e. ROW - Current row number.
- f. COL - Current column number.
- g. PSW - Print switch.
- h. LASTC - Print switch initiator column number.

3.8.6 INSERT

Subroutine INSERT accepts two column numbers, COL1 and COL2. It turns on all bits in the output buffer between these two columns inclusively. The output buffer for writing through themes consist of 32 two-byte words; therefore there are 512 bits, one per column.

First COL1 is checked for invalid values, then the word (1-32) and bit (1-16) positions for that column are calculated. If COL2 is less than or equal to COL1 the bit corresponding to COL1 is turned on and insert returns. Otherwise, all intermediate bits are turned on. Buffer words which are completely contained within the column limits are logically ORed with the logical mask 177777. Words which are to be partially filled are processed using the function FILL.

3.8.6.1 Argument List

- a. COL1 - Column for start fill.
- b. COL2 - Column for end fill.

3.8.6.2 Common Areas

- a. DBUF - See 3.8.1.1

3.8.6.3 Variables

- a. TEMP - Template for inserting symbol bit.
- b. WORD1 - Number of word contained in COL1.
- c. BIT1 - Bit position of COL1 in word number WORD1.
- d. MASK - Logical mask for insertion.
- e. WORD2 - Number of word containing COL2.
- f. BIT2 - Bit position of COL2 in word number WORD2.
- g. N - Number of words between WORD1 and WORD2.

3.8.7 FILL

FILL is a function subprogram which accepts two-bit positions and returns a logical mask which has those two bits and all bits between turned on. The total number of bits to be inserted is calculated and this number is used as an upper limit in a DO loop which performs a shift left one, add one operation. This enters the proper number of bits into the mask. The bits are then positioned correctly by shifting left (no add) a number of places equal to the bit number of the right-most bit.

3.8.7.1 Argument List

- a. BIT1 - Bit number of left-most bit.
- b. BIT2 - Bit number of right-most bit.

3.8.7.2 Common Areas

None

3.8.7.3 Variables

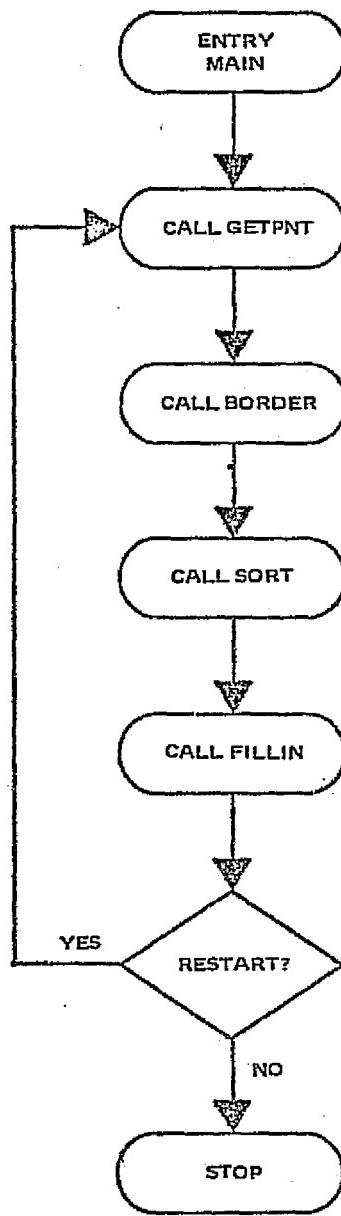
- a. NUM - Total number of add-shift operations.
- b. TEMP - Initial template.

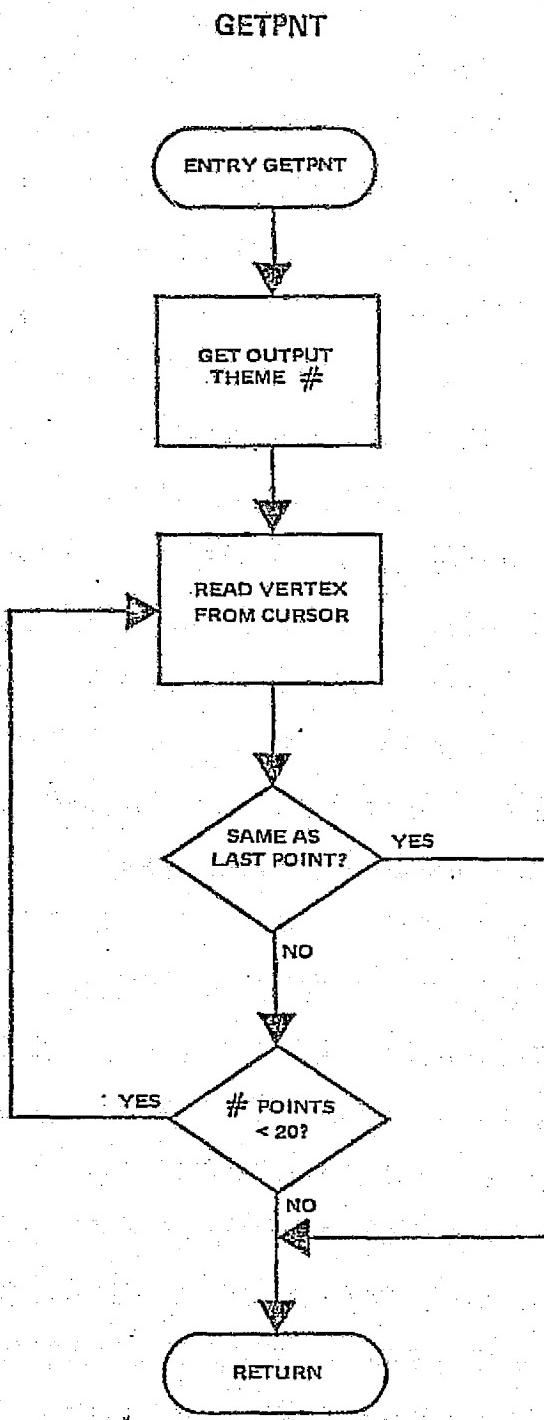
3.8.8 User's Guide

POLYGO is initiated by the MCR command RUN POLYGO \$. At execution time the user will be prompted for the following information.

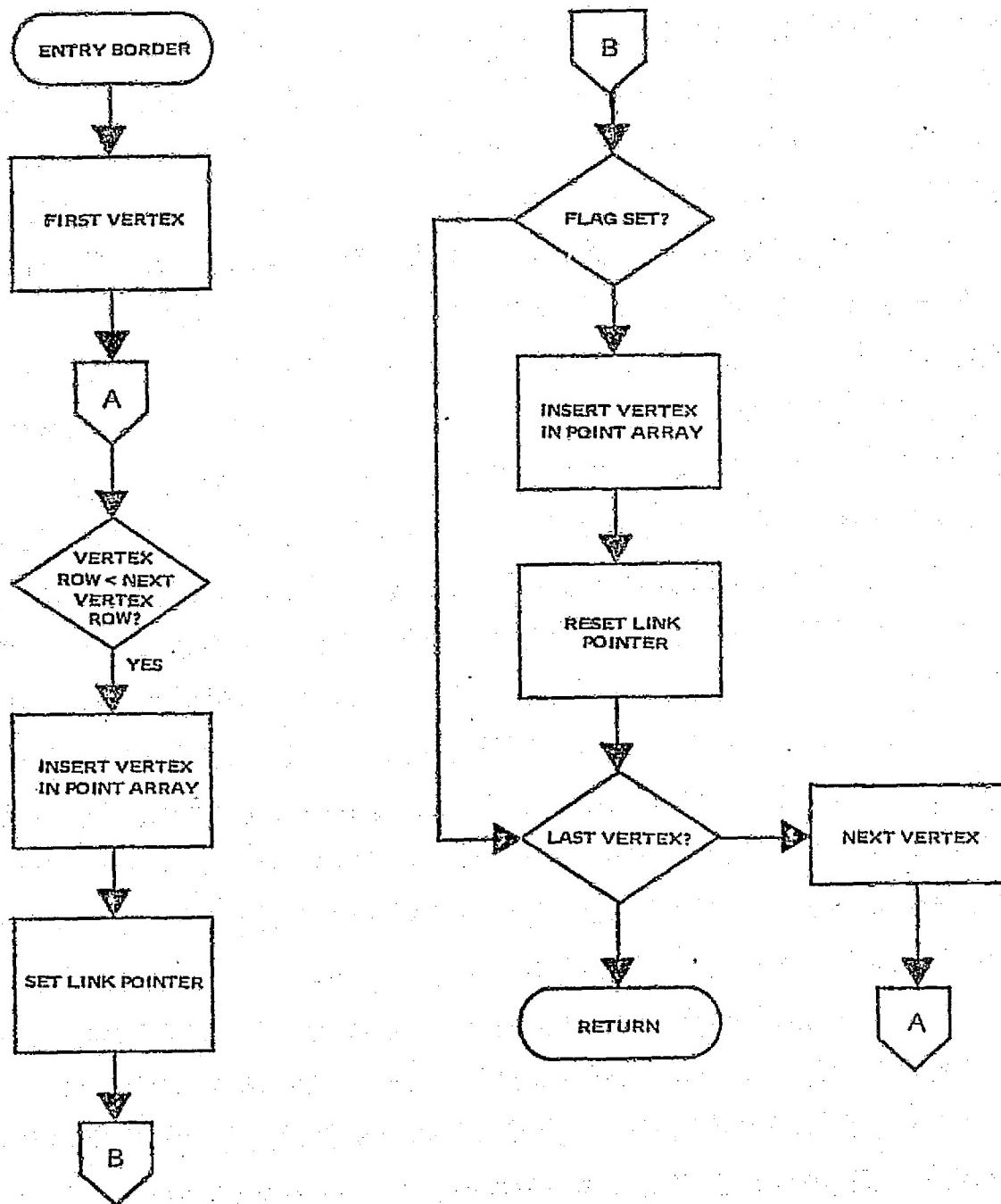
| <u>PROMPT</u> | <u>RESPONSE</u> |
|--------------------------|--|
| THEME NUMBER? > | Integer Value (1-8) |
| CURSOR > | Position Cursor, press carriage return to input vertex. Repeat last vertex to exit loop |
| (R) ESTART OR (E) XIT? > | R or E |

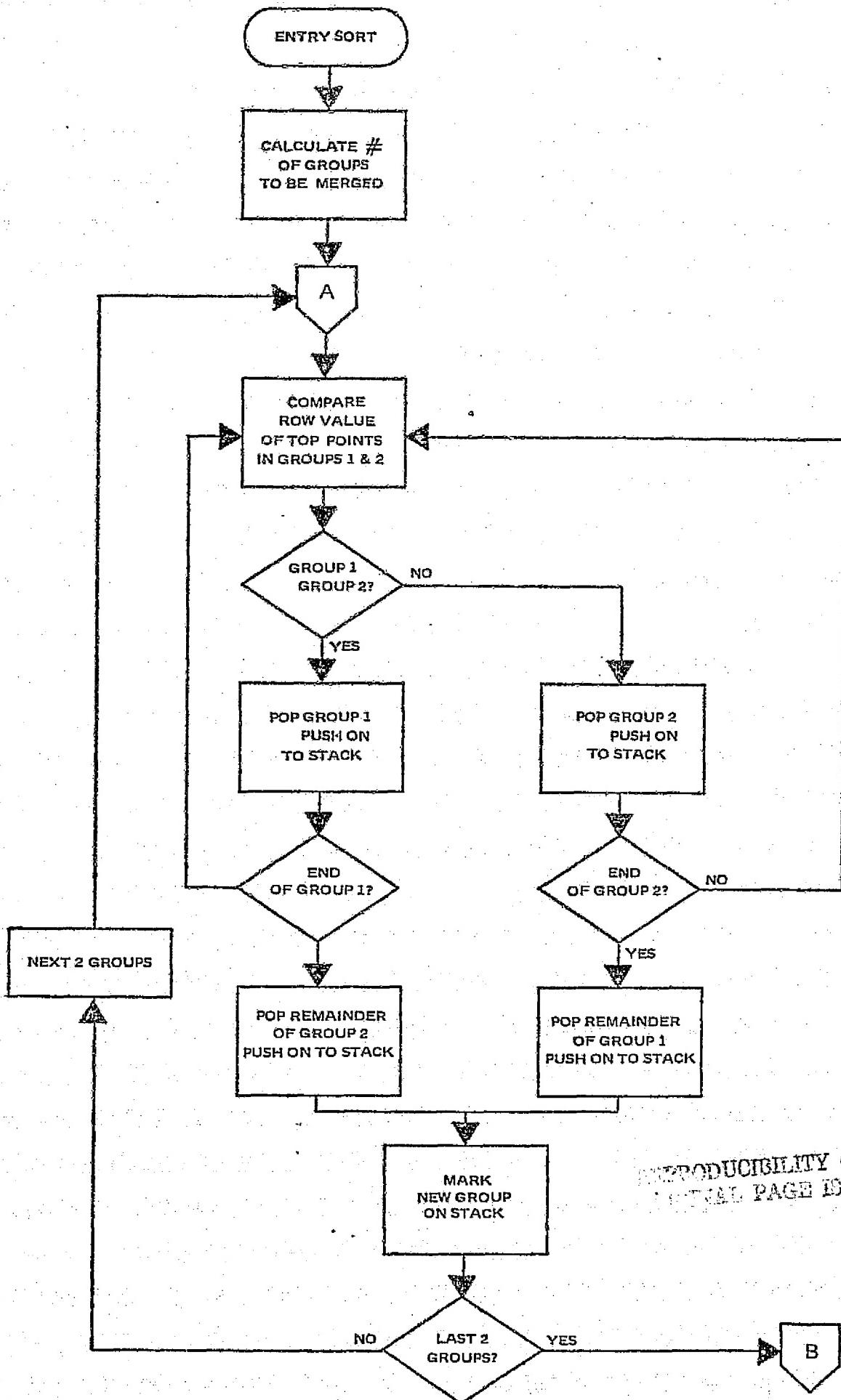
POLYGO

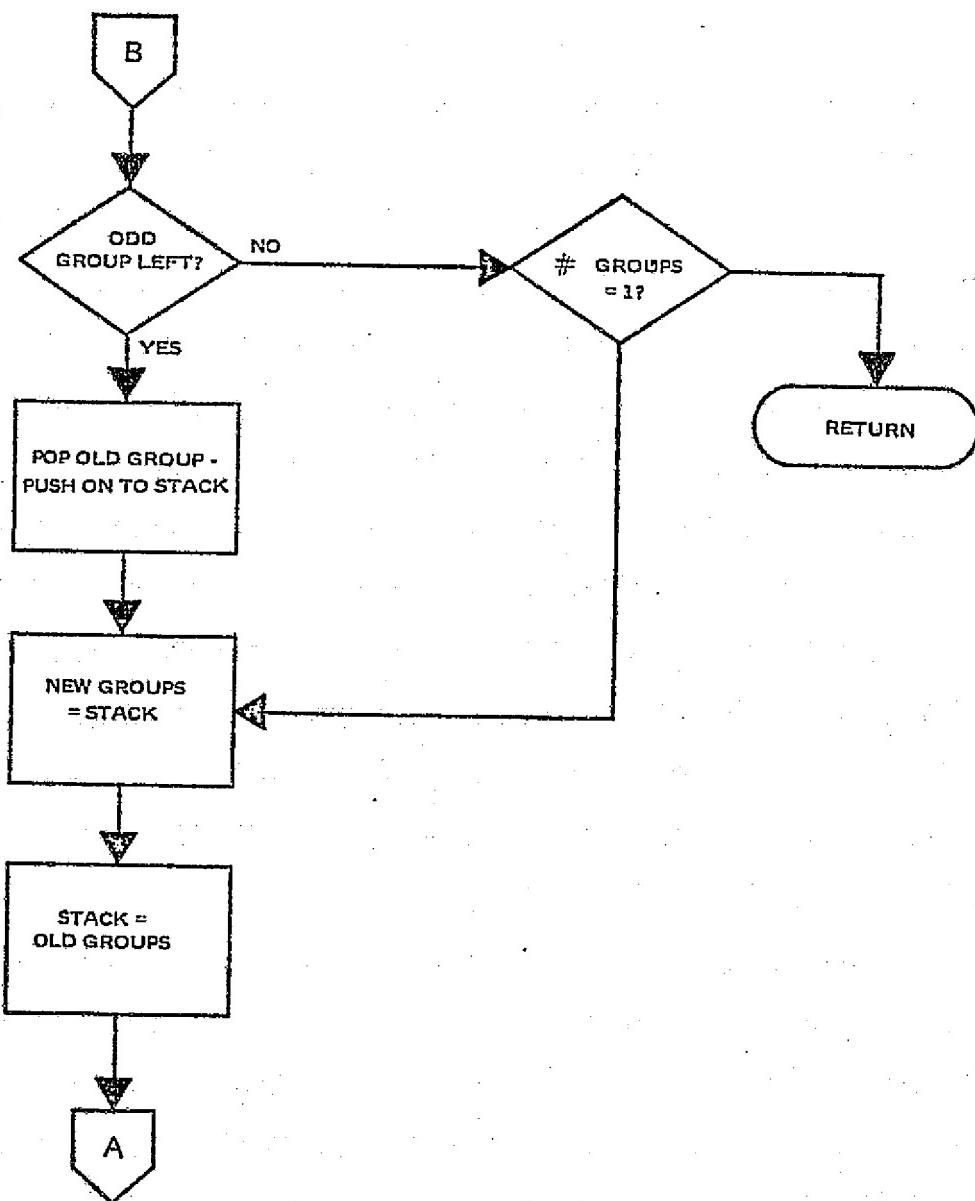




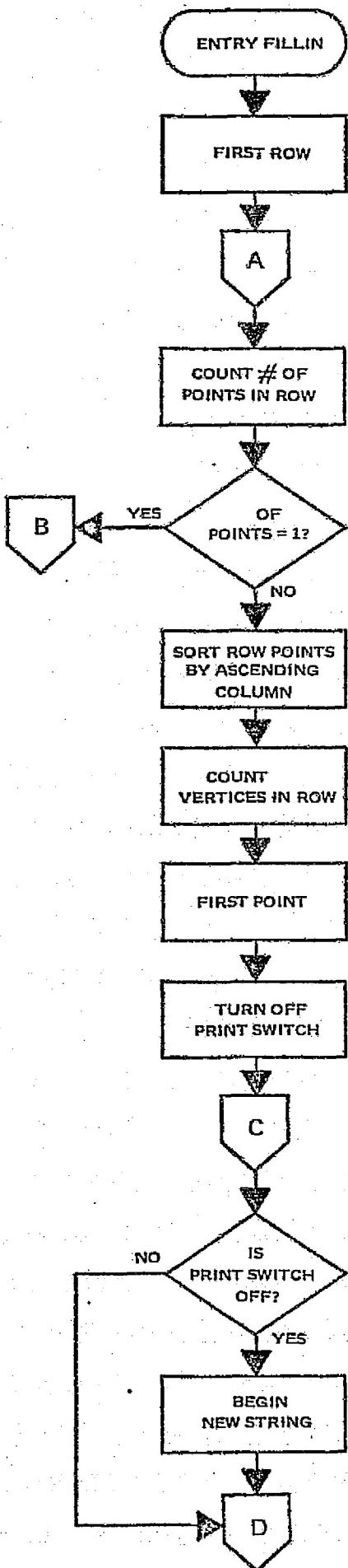
BORDER

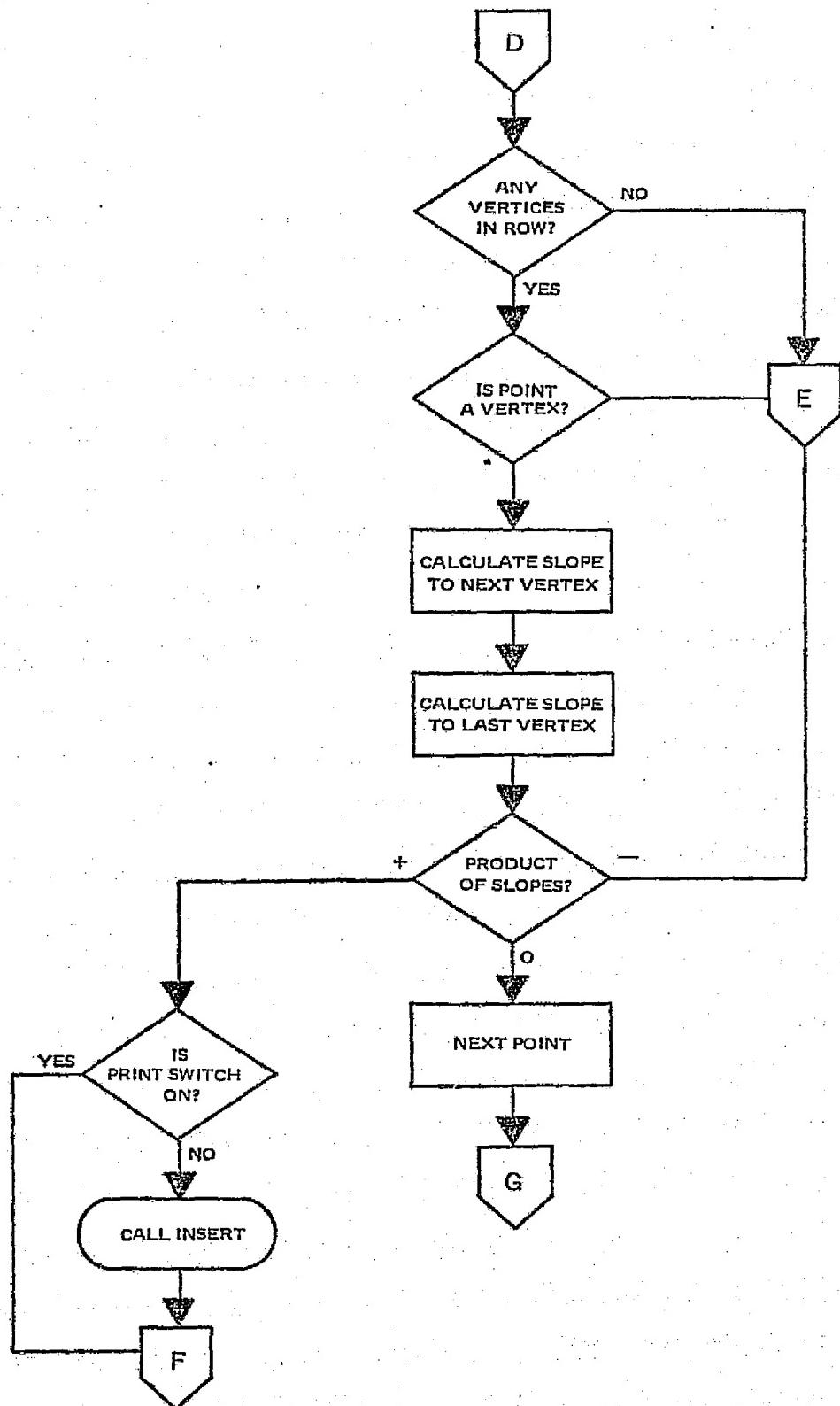


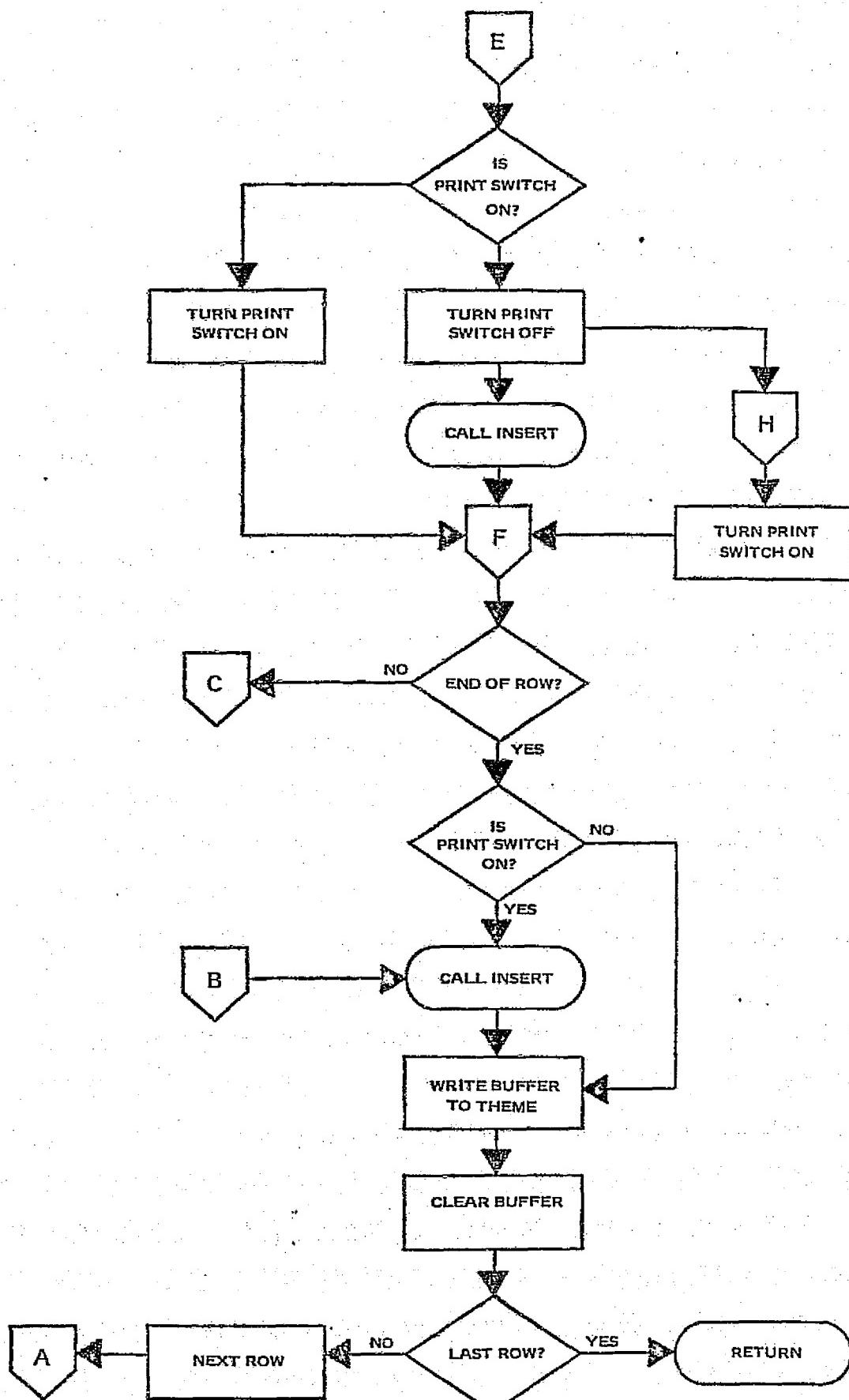


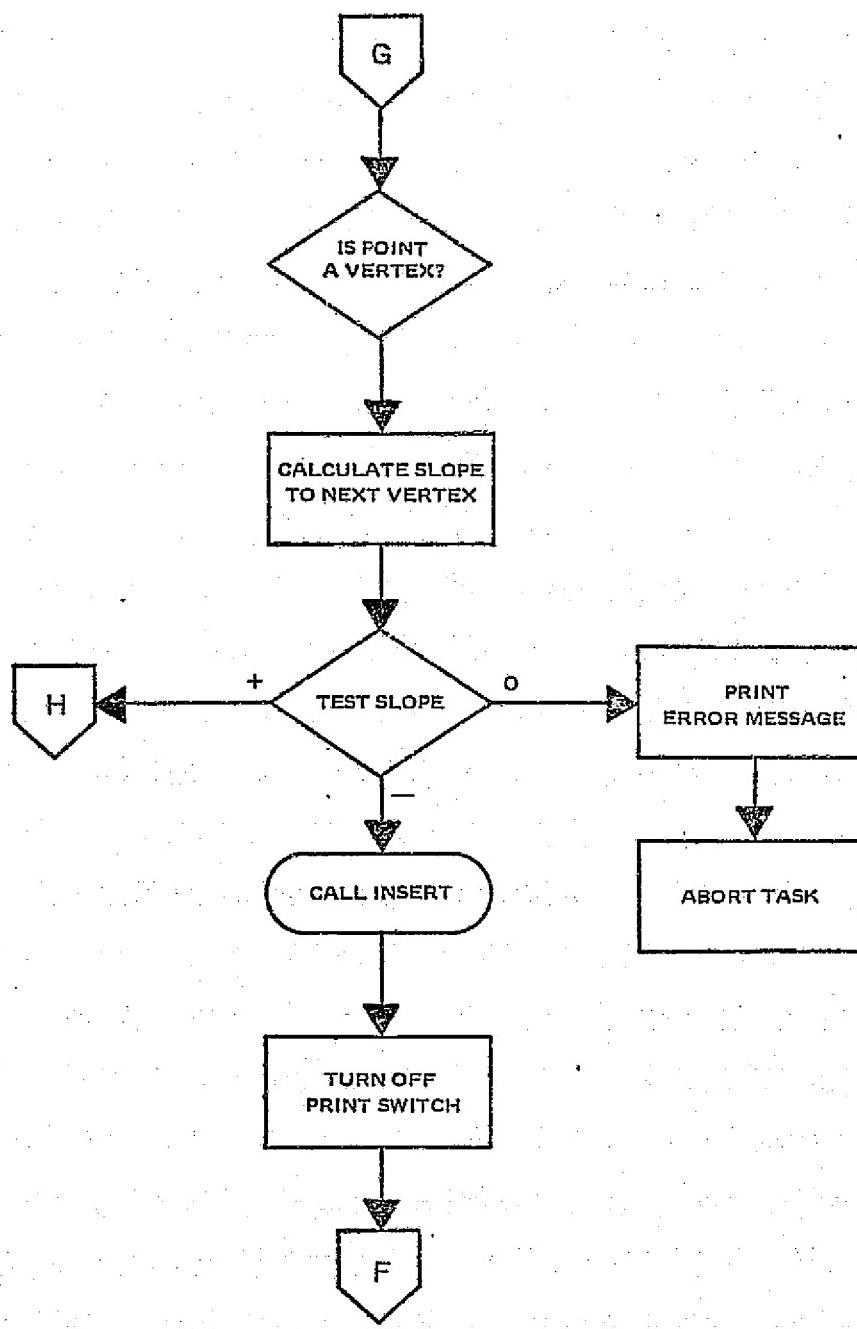


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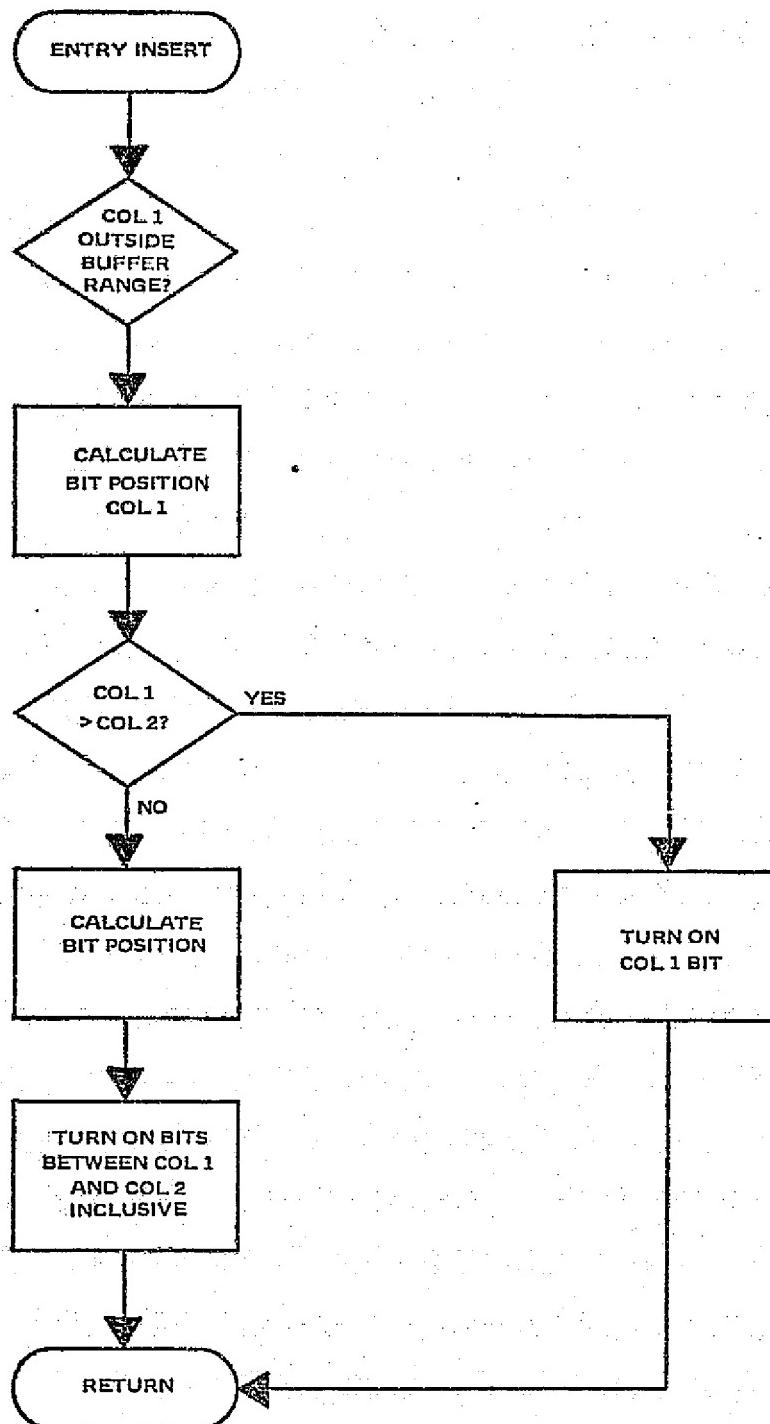








INSERT



3.9 SHADE

SHADE accepts an input window in image format with a maximum number of 250 columns and produces a shade print map of the image on a line printer. Shade requires a spooled line printer which is capable of printing at eight lines per inch.

Shading is accomplished by using triple strike characters. Two logical units are assign to LP:, one for each 125-character strip. Two options are available for choosing the character set.

1. Character set input manually through terminal.
2. Character set is assigned by program after scanning the image.

3.9.1 MAIN

MAIN opens the input data set and then calls GTWND to get the window coordinates. The user is then prompted for the character set option. If he chooses option one, GETSET is called and the character set is input from the terminal. If option two is chosen, SKIP is called to position the file, AUTOST is called to scan the image and assign the character set, and REREAD is called to reposition the file. Next, headers are written on the shade print and SKIP is again called to position the file at the beginning of the window.

I/O on the input file is performed with double buffering, so an initial call to READER is required before entering the loop which performs the actual processing. Upon entering the loop WAIT is called to wait for I/O completion and READER is called again to fill buffer number two. CRUNCH is now called to process buffer number one and produce one line of shade print. Next, WAIT is

called to wait for buffer number two, after which buffer number one is refilled by another call to READER. Buffer number two is processed by another call to CRUNCH and the loop restarts. After exiting from the loop, HHIST is called to produce a histogram of the input image on the line printer. The input is rewound in RWND and the task exits.

3.9.1.1 Common Areas

a. LUN

- 1. LUNI** - Input image Logical Unit Number
- 2. LUNO** - Not used
- 3. NIN** - Not used
- 4. NOUT** - Not used

b. ARRAY

- 1. ARRA1 (250)** - Output buffer number 1 for LP:
- 2. ARRA2 (250)** - Output buffer number 2 for LP:
- 3. ARRA3 (250)** - Output buffer number 3 for LP:
- 4. HIST (256)** - Image histogram.

c. VAL

- 1. VALUE1 (256)** - First strike character set.
- 2. VALUE2 (256)** - Second strike character set.
- 3. VALUE3 (256)** - Third strike character set.

d. LT125

1. CHECK - Flag, less than or equal to zero if number of columns is less than or equal to 125, greater than zero if number of columns greater than 125.
2. N - Last column of first strip.
3. COLSUM - Total number of columns output.
4. LABELR - Current row number.

e. WINDIN

1. ROW - Start row.
2. ROWSUM - Number of rows.
3. COLUMN - Start column.
4. NCOLS - Number of columns.

3.9.1.2 Variables

- a. LINE (256,2) - Two input buffers.
- b. IVAL - Stores ASCII code for blanks, used for output formating.
- c. LRECL - Maximum logical record length of input file.
- d. NSKIP - Number of rows to be skipped.
- e. KI - Actual input logical record length.

3.9.2 GETSET

GETSET provides a user interface for inputting the character set through the CRT. The user is prompted from the first 256 characters which make up the first of the triple strike character

set. The user types in any printable ASCII character followed by a repetition factor. After receiving 256 characters, GETSET will begin to prompt for the second set and then the third.

3.9.2.1 Argument List

- a. V(256,3) - Storage array for three 256-character vectors.

3.9.2.2 Common Areas

None

3.9.2.3 Variables

- a. NUM (3), INTEGER*4, stores header information.
- b. CHAR - ASCII character for input into character set.
- c. REP - Number of times CHAR is to be repeated.

3.9.3 AUTOST

AUTOST provides a means for assigning a standard character set through a given input image. The image is first scanned using subroutine SCAN and a histogram is accumulated of every fifth pixel in every fifth row. The histogram is then divided into eight equally populated regions to which each is assigned one of the eight standard triple strike characters.

3.9.3.1 Argument List

- a. V(256,3) - Storage array for three 256-character vectors.

3.9.3.2 Common Areas

- a. WINDIN - See 3.9.1.1
- b. ARRAY - See 3.9.1.1

3.9.3.3 Variables

- a. ISUM - Total histogram population.
- b. DIV - REAL*4, inverse of 1/8 of total histogram population.
- c. CHAR (3,8) - Stores eight standard triple strike characters.
- d. V - REAL*4, floating point equivalent of ISUM.
- e. ZZ - REAL*4, character number to assign to gray value.
- f. NCH - Integer equivalent of ZZ.

3.9.4 CRUNCH

Subroutine CRUNCH accepts one line of the input image, performs a table lookup into the character set using each gray value as an index, and constructs three buffers, one for each strike, for output to the line printer. As the processing takes place a histogram is also accumulated.

3.9.4.1 Argument List

- a. BUFFER (M2) - Image buffer.
- b. M1 - First word to be processed in buffer.
- c. M2 - Last word to be processed in buffer.

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3.9.4.2 Common Areas

- a. VAL - See 3.9.1.1
- b. ARRAY - See 3.9.1.1
- c. LT125 - See 3.9.1.1

3.9.4.3 Variables

- a. KK - Position pointer for output buffers.
- b. INEW - Index for table lookup.

3.9.5 User's Guide

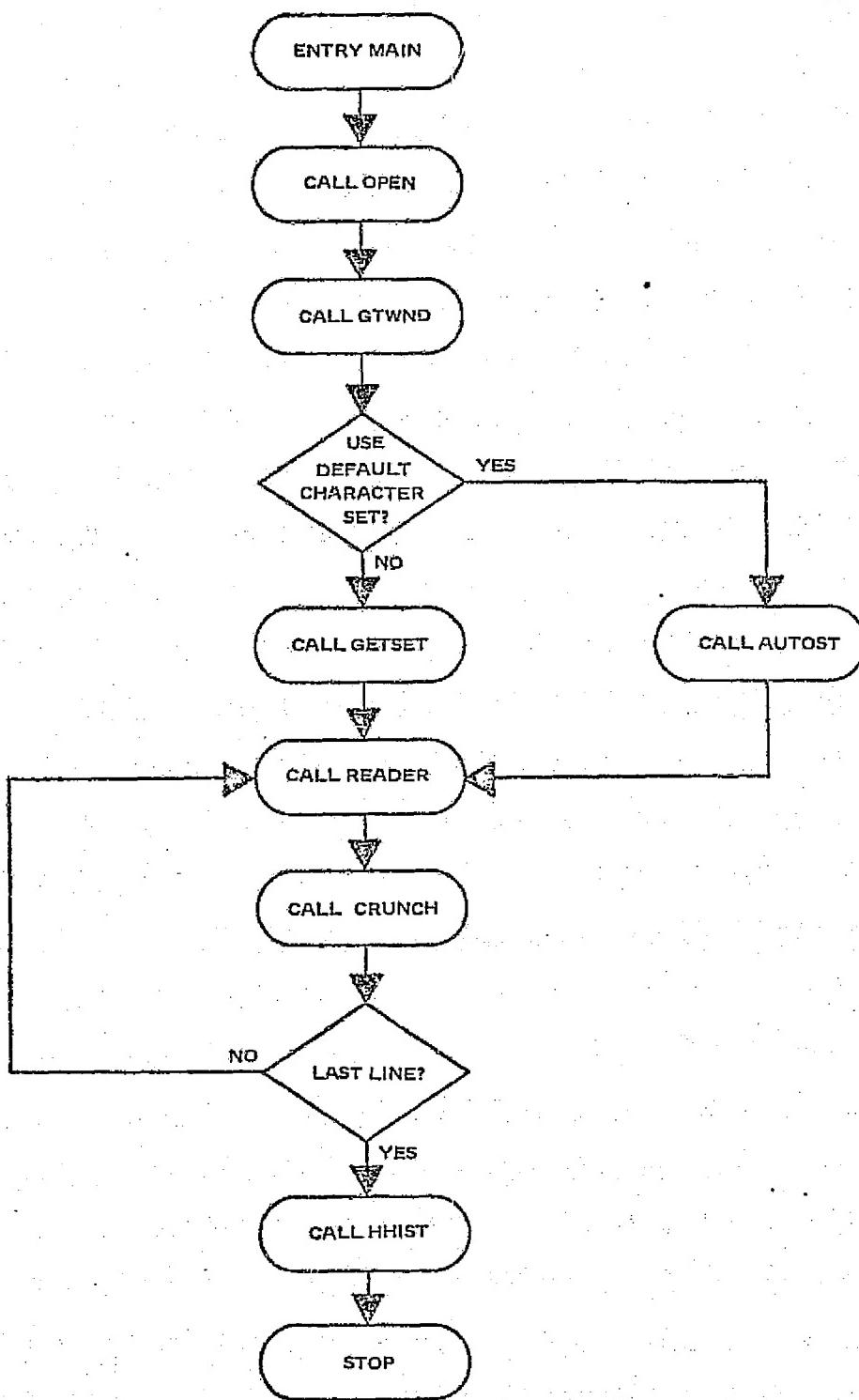
Shade is initiated by the MCR command RUN SHADE\$. In addition to the information required by OPEN (Section 2.1.4) and GTWND (Section 2.16.4), the user will be prompted for the following information.

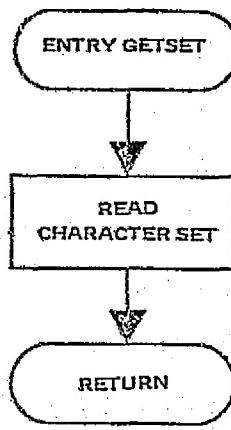
| <u>PROMPT</u> | <u>RESPONSE</u> |
|------------------------------|-----------------|
| USE DEFAULT CHARACTER SET? > | Y or N |

If the default character set is not desired the user must enter the character set on the control terminal.

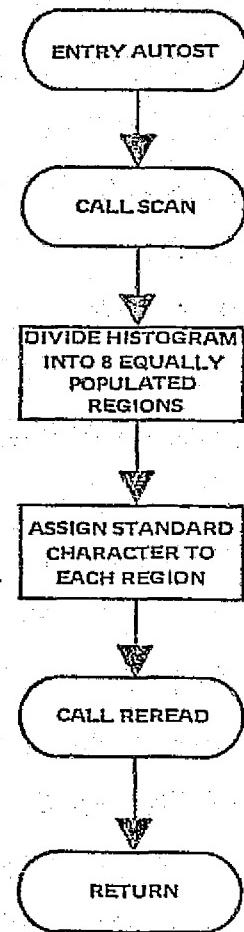
| <u>PROMPT</u> | <u>RESPONSE</u> |
|-----------------------------|-------------------------------|
| (1ST/2ND/3RD) CHARACTER SET | |
| CHARACTER? > | Any Printable ASCII Character |
| REPETITION? > | Integer Value (1-256) |

Shade will continue prompting until all three character sets are filled.

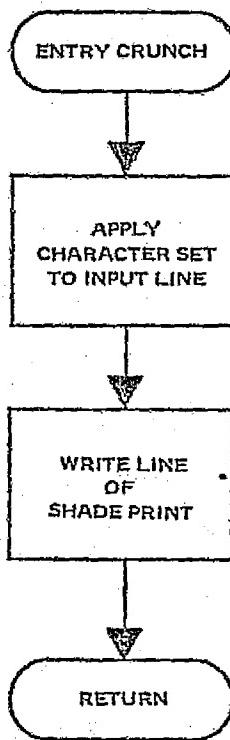




AUTOST



CRUNCH



3.10 EDGE

EDGE is a multi-purpose task which allows the user to replace each pixel in an image with a linear combination of the pixels in a 5×5 area centered around that pixel. Any linear combination using integer values is possible; thus the program can be used for edge enhancement, smoothing, or averaging, line enhancement, etc.

Two options are provided for the definition of the 5×5 kernel. The first option allows the user to specify an angle of edge enhancement from which the kernel is computed. The second option allows the user to manually specify each element of the 5×5 kernel. Both options also required a normalizing factor and an offset value so that the final pixel replacement value is

$$P = (K + O) \cdot N$$

where K is the result obtained by applying the 5×5 kernel, N is normalizing factor, and O is the offset. Any negative values are replaced by 0 and values over 255 are replaced by 255.

3.10.1 MAIN

First the user is prompted for the desired option number. For option number one SETKER is called and for option number two RDKER is called. When control returns to MAIN the kernel is typed on the screen of the terminal and the user has the option of continuing or exiting. If he desires to continue he is prompted for the normalizing factor, and offset GTWND is called to get the window coordinates and OPEN is called twice to open the input and output files. Finally, CONVLT is called to produce the output image.

3.10.1.1 Common Areas

a. LUN

1. LUNI - Input image Logical Unit Number.
2. LUNO - Output image Logical Unit Number.
3. NIN - Not used.
4. NOUT - Not used.

b. WIND

1. NROW - First row of input image.
2. NROWS - Number of rows of input image.
3. NCOL - First column of input image.
4. NCOLS - Number of columns of input image.

c. KERN

1. KER (5,5) - 5 x 5 kernel.
2. XNORM - Normalizing factor.
3. OFFSET - Offset values.

3.10.1.2 Variables

- a. OPTION - Option number (1 or 2).

3.10.2 SETKER

Subroutine SETKER prompts the user for a desired angle of enhancement and calculates a 5 x 5 kernel which will enhance edges which lie on or near that angle. A kernel will smooth in the perpendicular direction.

3.10.2.1 Arguments

None

3.10.2.2 Common Areas

- a. KERN - See 3.11.1.1

3.10.2.3 Variables

- a. ANGLE - REAL*4, Angle of enhancement.
- b. C - REAL*4, Cosine of ANGLE.
- c. S - REAL*4, Sine of ANGLE.

3.10.3 RDKER

Subroutine RDKER allows the user to manually type in any 5 x 5 kernel, one row at a time.

3.10.3.1 Arguments

None

3.10.3.2 Common Areas

- a. KERN - See 3.11.1.1

3.10.4 CONVLT

Subroutine CONVLT applies to previously defined kernel to the input image and produces the output image. Five lines of the input image are needed to produce a line of the output image; therefore, five input buffers are needed.

After calculating the buffer length the first five lines of the input are read. After each line is read it is expanded to one pixel per full word format in STRETCH. Next the main loop where the processing takes place is entered. First READER is called to issue an I/O request for a new input line which will be used the next time through the loop. The kernel is now applied to the five

lines which have already been expanded. As each new pixel is generated it is checked for a negative value. All negative pixels are set to 0. Then the pixel is divided by the normalizing factor and the results are checked for a value greater than 255. If found the pixel is set equal to 55 to avoid wrap around. STORIT is called to place the new pixel in the correct position of the output buffer. After the new line is completed the buffer pointers which indicate the order in which the buffer were filled are rotated and WRITER is called to write the new line. After the entire window has been processed, EOF is called to write an end of file mark on the new file, and both input and output files are rewound.

3.10.4.1 Argument List

None

3.10.4.2 Common Areas

- a. LUN - See 3.11.1.1
- b. KERN - See 3.11.1.1
- c. POINT
 1. L1 - Buffer pointer number one.
 2. L2 - Buffer pointer number two.
 3. L3 - Buffer pointer number three.
 4. L4 - Buffer pointer number four.
 5. L5 - Buffer pointer number five.
- d. DBUF
 1. BUFF1 (256) - Input buffer.
 2. BUFF2 (256) - Output buffer.
- e. WIND - See 3.11.1.1

3.10.4.3 Variables

- a. BLEN - Output buffer lengths.
- b. BUflen - Input buffer lengths.
- c. PIXEL (512,5) - Expanded input buffers.
- d. ISUM - New gray value.

3.10.5 ROTATE

Subroutine ROTATE cycles the buffer pointers which indicate which input line is contained in each buffer.

3.11.5.1 Argument List

None

3.10.5.2 Common Areas

- a. POINT - See 3.11.5.2

3.10.6 STRETCH

Subroutine STRETCH accepts a line in the input image in the form of one pixel per byte and expands it into the form of one pixel per word.

3.10.6.1 Argument List

- a. BUFFIN (256) - Input buffer.
- b. LINE (D1,D2) - Output buffers.
- c. NUM - Number of output buffer to be filled.
- d. D1 - Output buffer dimension number one.
- e. D2 - Output buffer dimension number two.

3.10.6.2 Common Areas

- a. WIND - See 3.11.1.1

3.10.6.3 Variables

- a. NWORD - Number of words to be processed.

3.10.7 STORIT

Subroutine STORIT accepts a pixel in a buffer position and inserts that pixel in the specify position of the output buffer.

3.10.7.1 Argument List

- a. PIX - Pixel to be stored.
- b. NUM - Column number of pixels.

3.10.7.2 Common Areas

- a. DBUF - See 3.11.5.2
- b. WIND - See 3.11.1.1

3.10.7.3 Variables

- a. INDX - Output word number of pixels.

3.10.8 User's Guide

EDGE is initiated by the MCR command RUN EDGE\$. In addition to the information requested by OPEN (Section 2.1.4) and GTWND (Section 2.16.4), the user will be requested to supply the following information.

PROMPT

RESPONSE

OPTION DESIRED? >

1 or 2

if option one is chosen

ENHANCEMENT ANGLE ($^{\circ}$) =

Floating point value

if option two is chosen

FIRST ROW >

5 integer values separated by commas.

SECOND ROW >

5 integer values separated by commas.

THIRD ROW >

5 integer values separated by commas.

FOURTH ROW >

5 integer values separated by commas.

FIFTH ROW >

5 integer values separated by commas.

for both options

NORMALIZING FACTOR? >

Integer value.

OFFSET? >

Integer value.

TYPE IN ORIGINAL MINIMUM AND MAXIMUM GRAY VALUES >

Integer (0-255), Integer (0-255)

TYPE IN FINAL MINIMUM AND MAXIMUM GRAY VALUES >

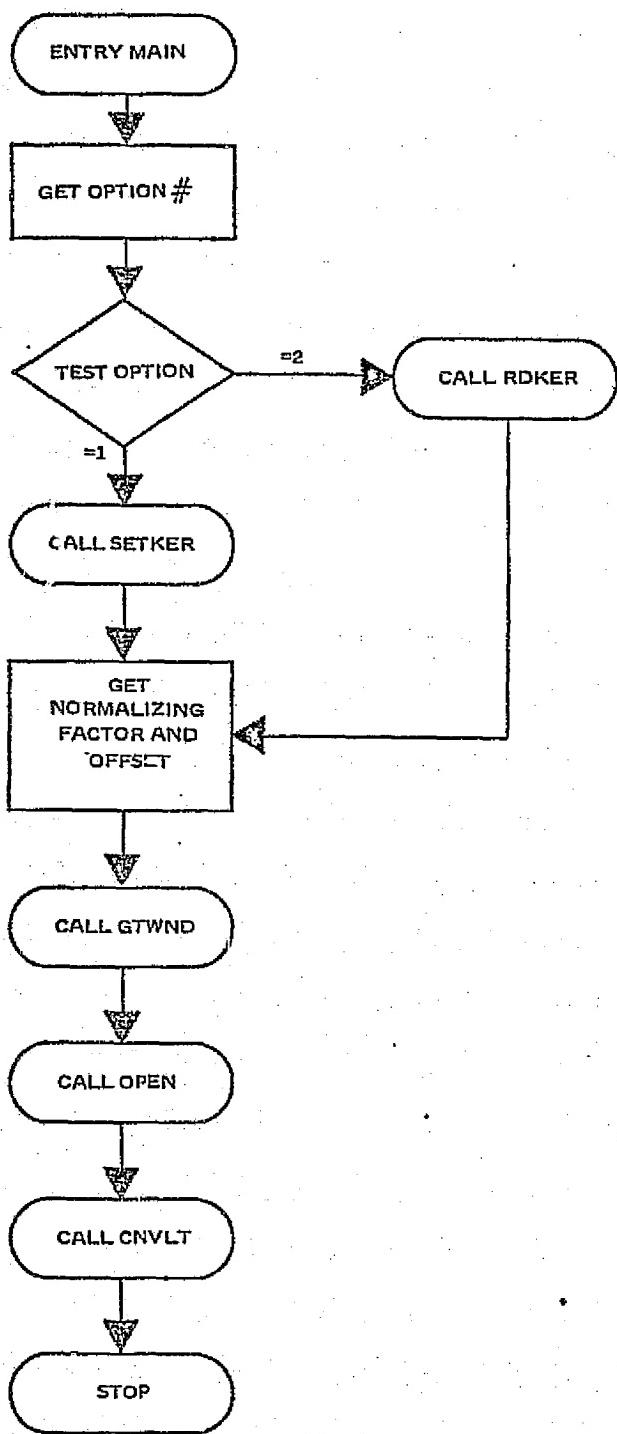
Integer (0-255), Integer (0-255)

for option #5

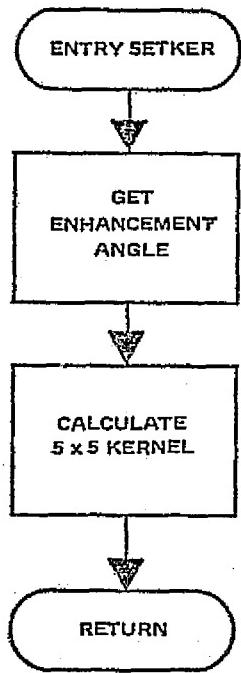
SPREAD FACTOR? >

Integer (1-100) or carriage return for default of 66%

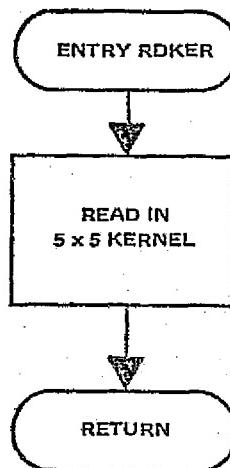
EDGE



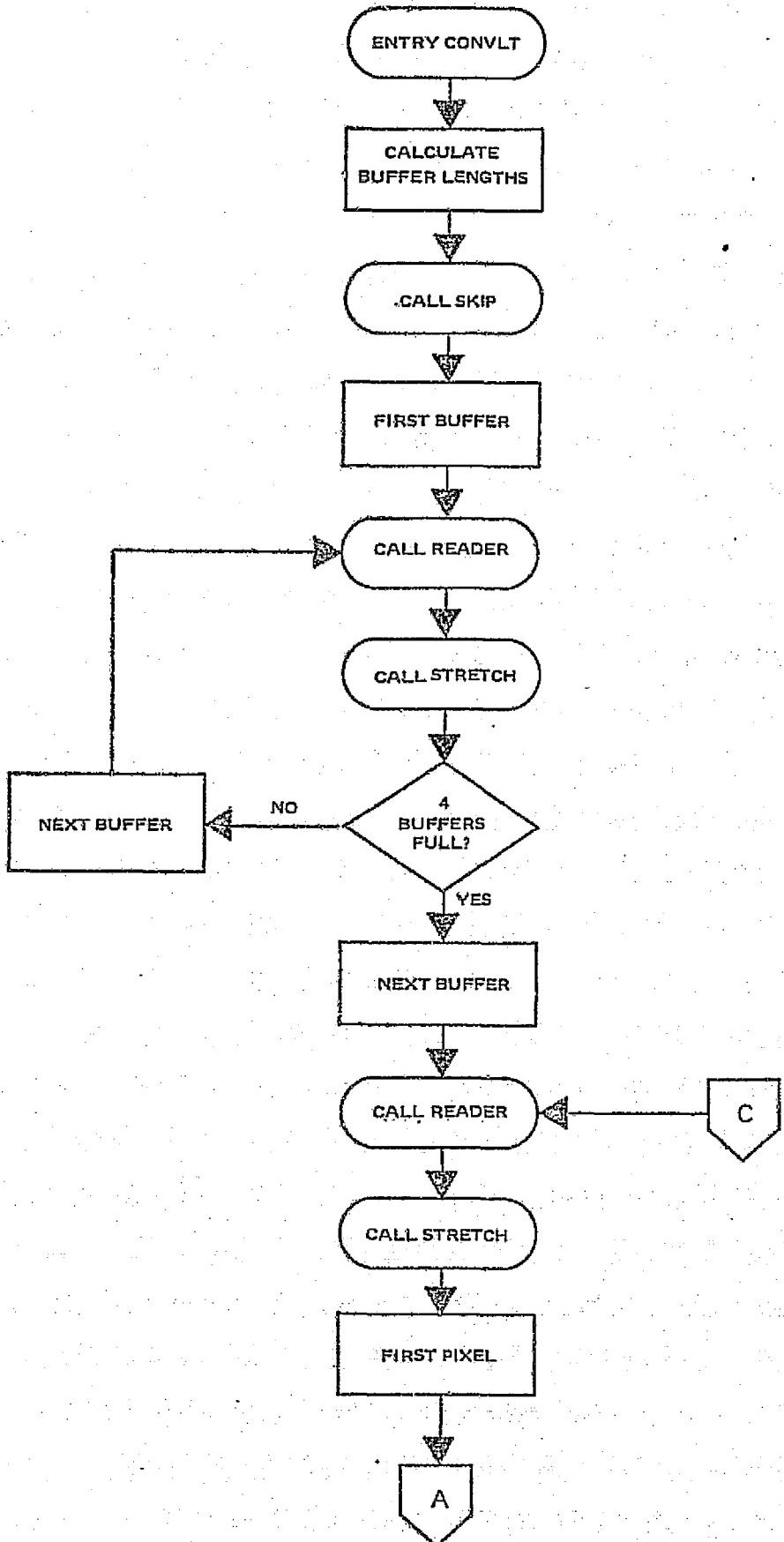
SETKER



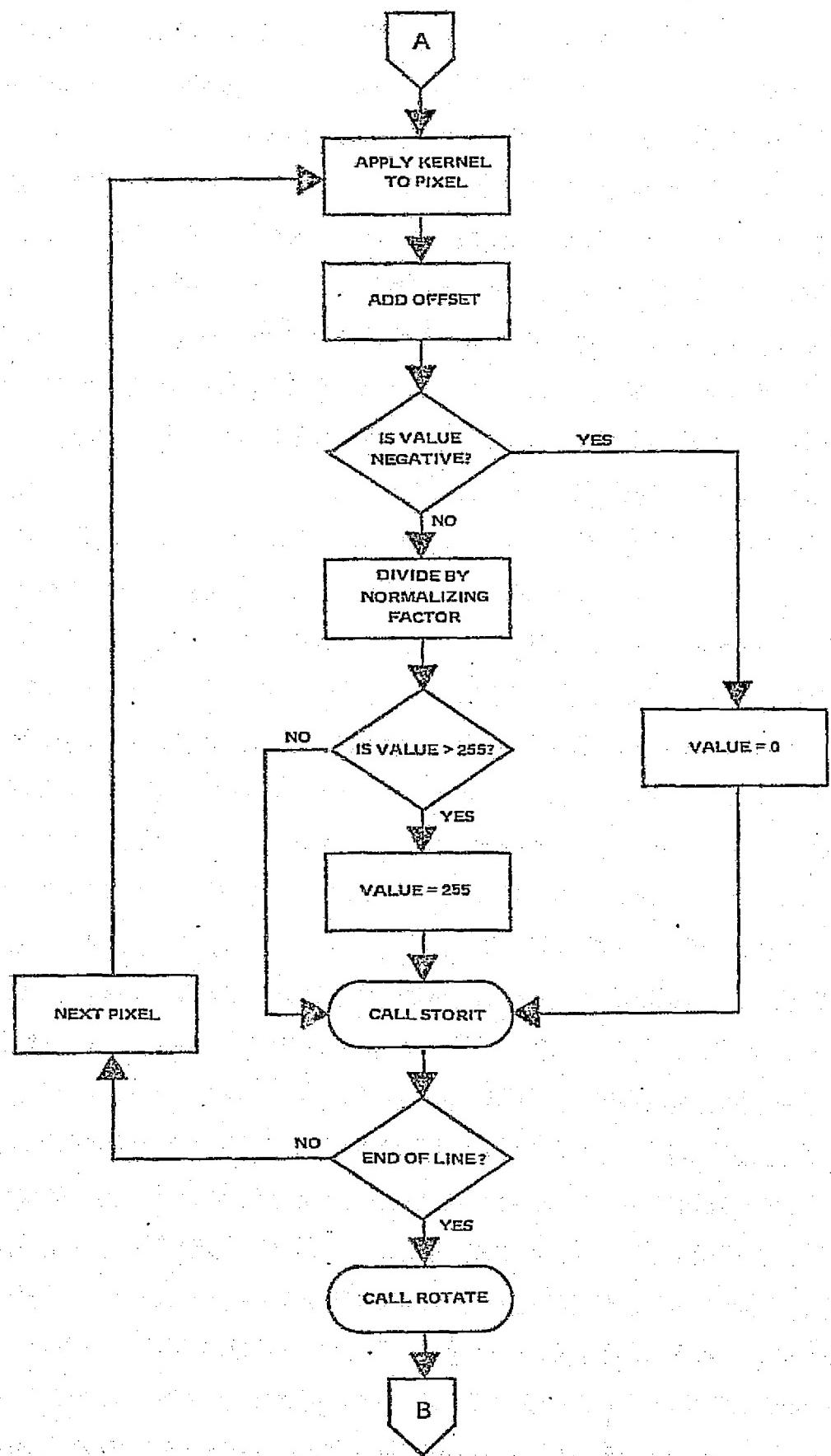
RDKER

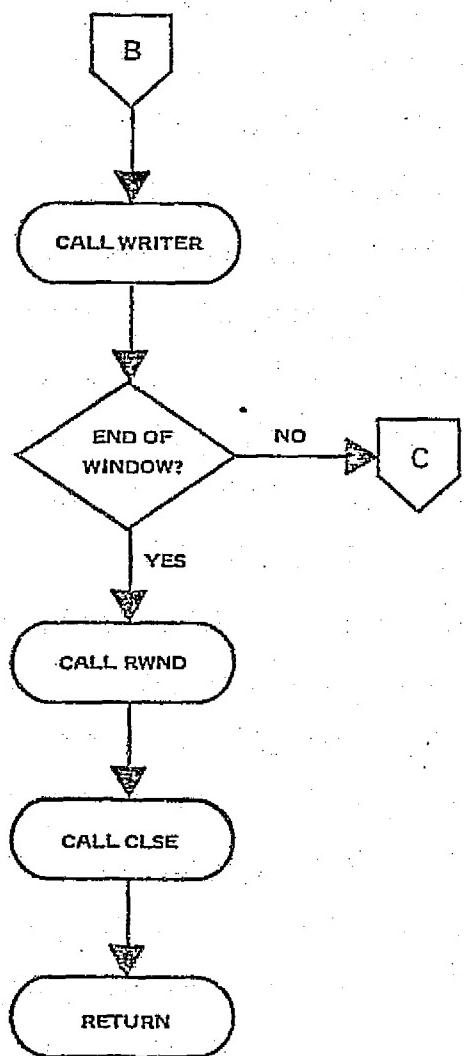


CONVLT

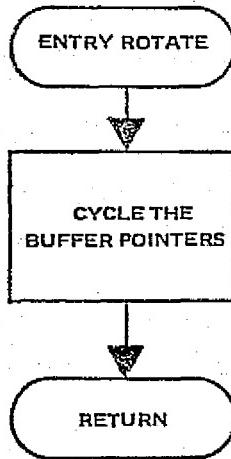


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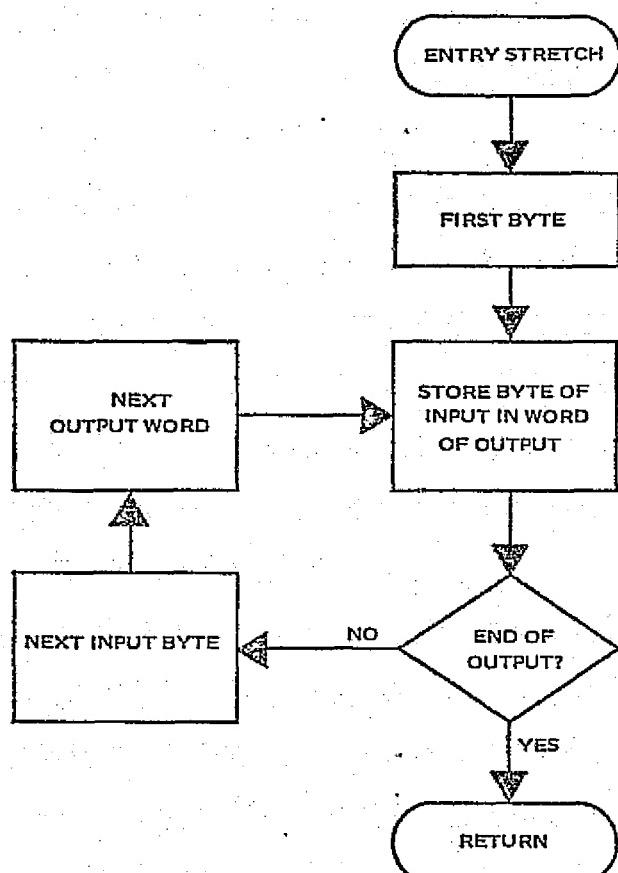




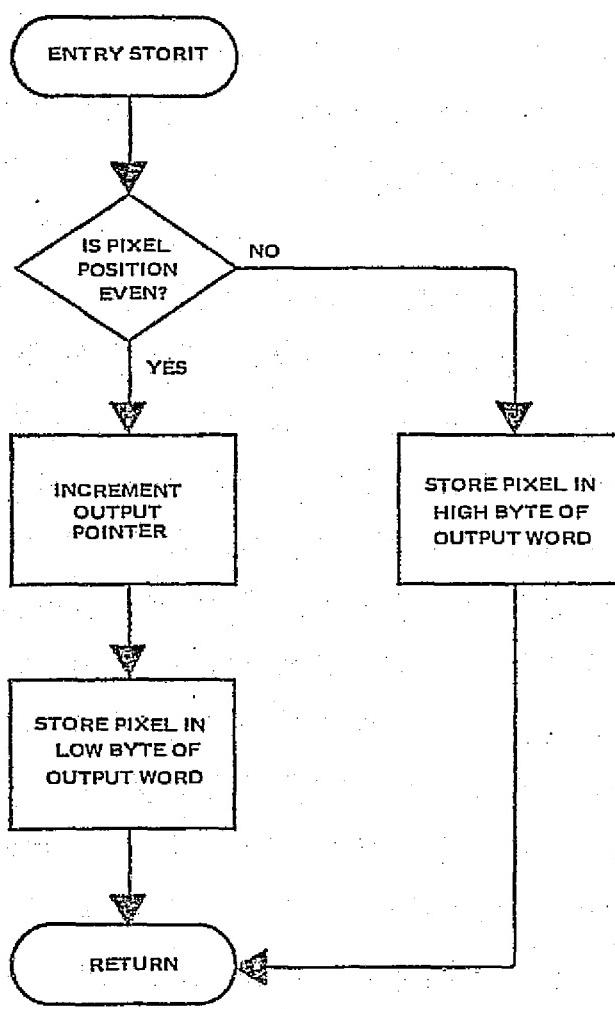
ROTATE



STRETCH



STORIT



3.11 HHIST

Subroutine HHIST accepts as input a 256 - bin histogram which it displays in graphic form. There are 128 columns of histogram output, so pairs of consecutive bins in the original histogram are merged to form one column of output. The histogram output contains a fixed number of rows, and the subroutine will automatically scale the data to fit in the allotted space. This scaling is effected by setting each character on the histogram equal to a certain number of occurrences. The number of remaining pixels in each bin (once the largest possible multiple of the scaling factor has been subtracted) is shown by a character on top of each bin in the printed histogram.

3.11.1 Argument List

- a. HIST (256) - input histogram

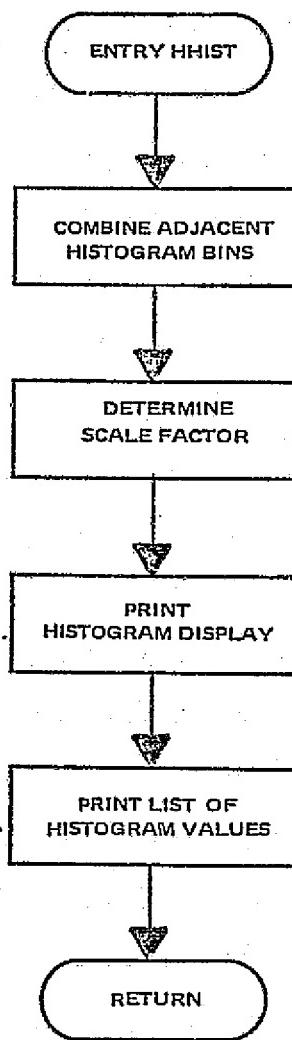
3.11.2 Common Areas

- None

3.11.3 Variables

- a. NMAX - maximum value of histogram
- b. INC - histogram scale factor

HIST



3.12 REGISTER

See AFYNE (4.9.2)

3.13 CONTOURS

See GRAY (3.1)

3.14 LINE

See EDGE (3.10)

3.15 COMBINE

See BESTBAND (3.6)

4.0 DATA MANAGEMENT SOFTWARE

4.1 CINDEX

CINDEX contains the initial steps of the data base creation sequence, creation of the label and index file. The program accepts the data base dimensions in the form of maximum and minimum coordinates. From this information, the storage requirements are calculated and displayed on the terminal. At this point, final operator approval is necessary for file generation. Upon approval, the label file is created and the index file label is inserted. Finally, the index file is created and the header and one 8-byte record for each I,J is inserted.

4.1.1 Common Areas - None

4.1.2 Variables

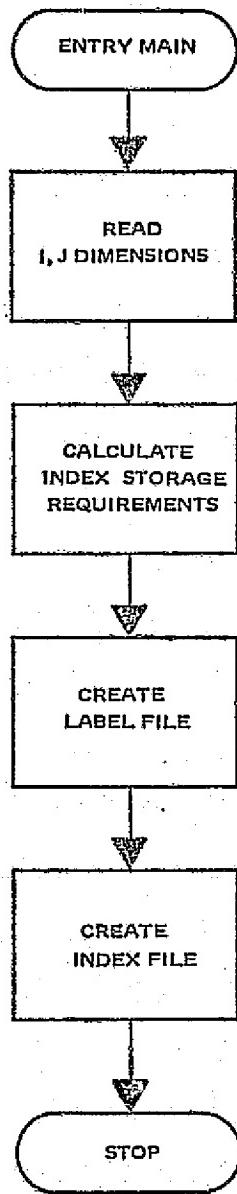
- a. LBL1 (4) - LOGICAL*I, Use to store ASCII file type qualifier '.LBL'
- b. LBL2 (4) - LOGICAL*I, used to store ASCII file type qualifier '.IDX'
- c. FILE (18) - LOGICAL*I, ASCII file name
- d. IMIN - Minimum I value in data base
- e. NUMI - Number of I values in data base
- f. JMIN - Minimum J value in data base
- g. NUMJ - Number of J values in data base
- h. NBLK - Number of blocks of index file storage
- i. IDEV - ASCII device name
- j. IUNG - Physical device number
- k. LUN - Logical Unit Number
- l. LRECP - Index file record length

- m. NREC - INTEGER*4, number of records in the index file
- n. NBYT - INTEGER*4, number of bytes in the index file
- o. BUFF (2) - INTEGER*4, I/O buffer for index file
- p. V - INTEGER*4, associate variable for index file

4.1.3 User's Guide

| <u>PROMPT</u> | <u>RESPONSE</u> |
|-------------------|---------------------------------|
| MINIMUM I VALUE?> | Three-digit integer value |
| MAXIMUM I VALUE?> | Three-digit integer value |
| MINIMUM J VALUE?> | Three-digit integer value |
| MAXIMUM J VALUE?> | Three-digit integer value |
| CONTINUE?> | Y or N |
| DATA BASE NAME?> | Nine-character ASCII name |
| DEVICE?> | Two-character ASCII device name |
| UNIT NUMBER?> | Physical unit number of device |

CINDEX



4.2 POLYB

POLYB accepts the LAT, LON vertices of each sub-basin in the watershed area, determines which cells lie within each sub-basin and inserts the basin's numbers in the index records. CINDEX must be run before running this program.

4.2.1 MAIN

For each sub-basin, POLYB will accept up to 20 vertices in the form of latitude and longitude. Each vertex is transformed into I,J coordinates which are multiplied by two before truncation to preserve the K coordinates. Next, adjacent vertices are connected using subroutine BORDER. Subroutine SORT sorts all border points by J number and subroutine FILLIN fills in interior points for each J row. These three subroutines are described in Section 3.8 under POLYGO.

As each row is filled-in, subroutine INSERTB is called to enter the basin numbers in the index file. This subroutine is passed an initial I, a final I, and a J value, each doubled to preserve K values. INSERTB determines which K cells lie within the specified limits and inserts the current basin number in the index record for each of them. After each sub-basin is complete, the user has the option of restarting or exiting.

4.2.1.1 Common Areas

a. VTX

1. POINT (2,1000,2) - Storage for up to 1,000 border coordinate pairs

2. NPT - Number of coordinate pairs stored in POINT
3. VERTEX (2,20) - Used to store up to 20 vertex coordinate pairs
4. NVTX - Number of vertex coordinate pairs stored in VERTEX
5. LINK (21) - Points into POINT for purposes of merge sorting

b. INDEX

1. NRECP - INTEGER*4, number of records in index file
2. P - INTEGER*4, associate variable for the index file
3. LUNI - Logical Unit Number
4. LRECP - Record length of index records
5. IMIN - First I value in index file
6. NUMI - Number of I values in the index file
7. JMIN - First J value in index file
8. NUMJ - Number of J values in index file

4.2.1.2 Variables

- a. PT1 (2,1000) - Array used by EQUIVALENCE statement to format POINT
- b. PT2 (2,1000) - Array used by EQUIVALENCE statement to format POINT
- c. N - Used by SORT to indicate in which half of POINT the sorted array resides

4.2.2 GETPNT

GETPNT is an interface module which accepts a basin number and a set of basin vertices in the form of latitude and longitude coordinates. As each coordinate pair is accepted, it is mapped into the WMO grid. The resulting floating point I,J pair is multiplied by two before being converted into integer in VERTEX. This avoids truncation of the fraction which determines the K cell number.

4.2.2.1 Argument List

None

4.2.2.2 Common Areas

- a. VTX - See 4.2.1.1
- b. NTHM

 1. THEME - Not used in this task
 2. NBASIN - Basin number of polygon

4.2.2.3 Variables

- a. IPT - Stores unscaled I coordinate for output to terminal
- b. JPT - Stores unscaled J coordinate for output to terminal
- c. XLAT - REAL*4, latitude of basin vertex
- d. XLON - REAL*4, longitude of basin vertex
- e. XB - REAL*4, conversion constant used for mapping into WMO grid
- f. X - REAL*4, conversion constant used for mapping into WMO grid

- g. XI - REAL*4, result of WMO mapping, I coordinate
- h. XJ - REAL*4, result of mapping, J coordinate

4.2.3 INSERT

INSERT accepts first and last I values and a J value, determines which K cells lie within these bounds and inserts the appropriate basin numbers in the index file for these cells. The I and J values as received by INSERT are doubled and the true I,J,K's are extracted as follows:

$$I = I'/2$$

$$J = J'/2$$

Next INSERT determines if the first I,J is completely contained in the row. If K equals two or three, the cell is completely contained and basin numbers may be inserted in both. If K equals one or four, only half the cell is contained. Interior cells are obviously completely contained. The last I,J is the reverse of the first. If K equals one or four, the cell is completely contained and if K equals two or three, it is only partially contained.

4.2.3.1 Agrument List

- a. COL1 - First I coordinate
- b. COL2 - Last I coordinate
- c. J - J coordinate

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4.2.3.2 Common Areas

- a. INDEX - See 4.2.1.1
- b. NTHM - See 4.2.2.2

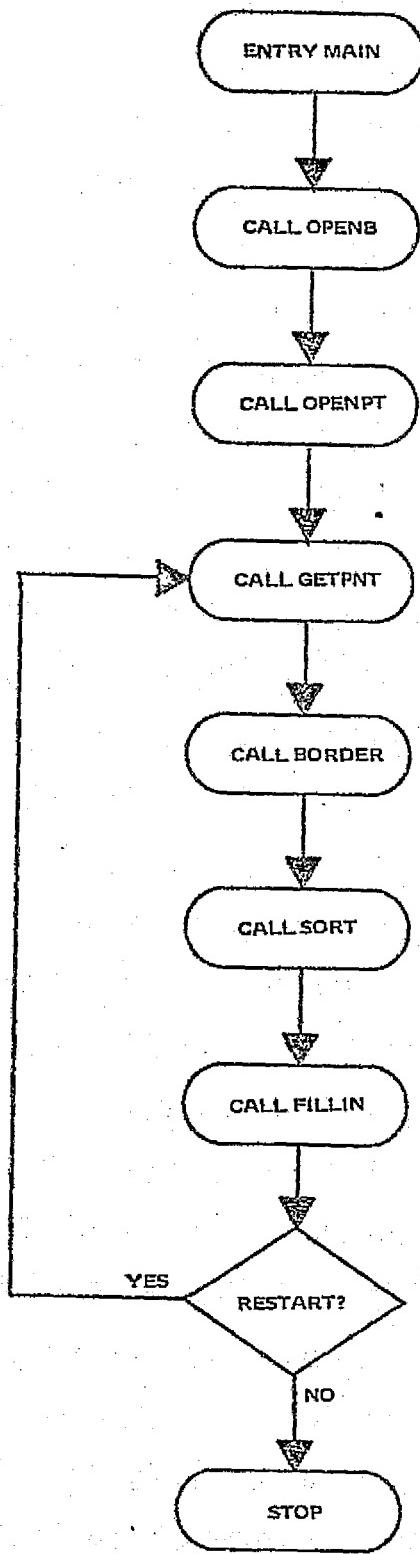
4.2.3.3 Variables

- a. IOFF - INTEGER*4, points to record number in index file of beginning of current J row
- b. MASK (2) - Logical masks
- c. HBASIN (2) - Logical masks used to insert basin number in either high order byte or low order byte of a word
- d. KBASIN - Stores basin number in both high and low order bytes.
- e. IFIRST - First I coordinate of row
- f. ILAST - Last I coordinate of row
- g. JROW - J coordinate of row
- h. KCOL1 - Flag, equals zero if COL1 is even,
equals one if COL1 is odd
- i. KCOL2 - Flag, equals zero if COL2 is even,
equals one if COL2 is odd
- j. KROW - Flag, equals zero if J is even, one if J
is odd
- k. INDX - Pointer into I/O buffer for index file.
Points to first word if K equals one or two,
second word if K equals three or four
- l. BUFF (4) - I/O buffer for index file
- m. NDX - Pointer into HBASIN and MASK vectors

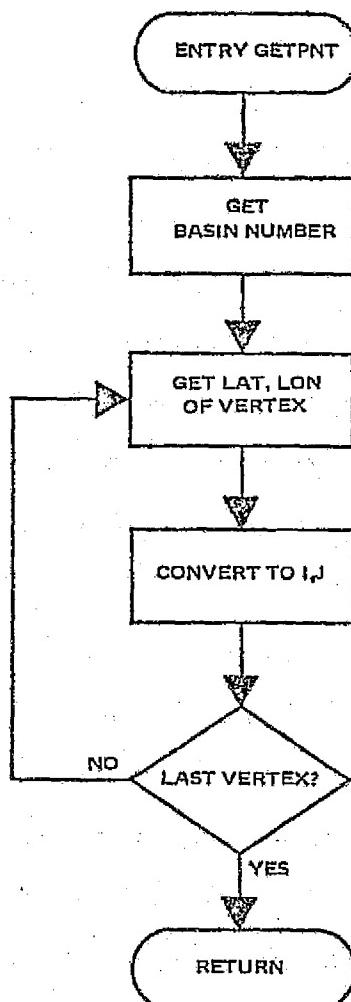
4.2.4 User's Guide

| <u>PROMPT</u> | <u>RESPONSE</u> |
|------------------|--|
| DATA BASE NAME?> | Nine-character alphanumeric name |
| DEVICE NAME?> | Two-character alphanumeric name |
| UNIT NUMBER?> | One-digit integer |
| BASIN NUMBER?> | Integer number (1-8) |
| LAT,LON?> | Two floating point numbers (F12.4) separated by a comma or carriage return to exit |

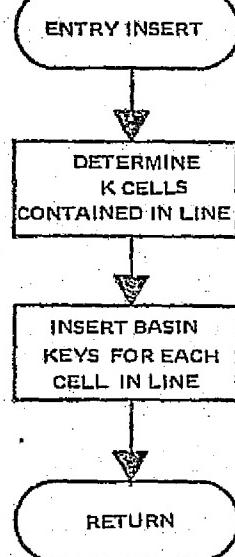
POLYB



GETPNT



INSERT



4.3 CDATA

CDATA is used to generate the archive and daily cell files either simultaneously or individually. The program assumes that the index file has been created and the basin keys have been inserted.

CDATA first searches the index file to determine the populated I,J's. This information along with the record length and number of dates (for daily), is used to define storage requirements. Then depending on user inputs, the program proceeds to create the archive or daily files or both, inserting one record with I,J,K and basin numbers for each K cell (and for each date in daily files).

4.3.1 Common Areas - None

4.3.2 Description of Variables

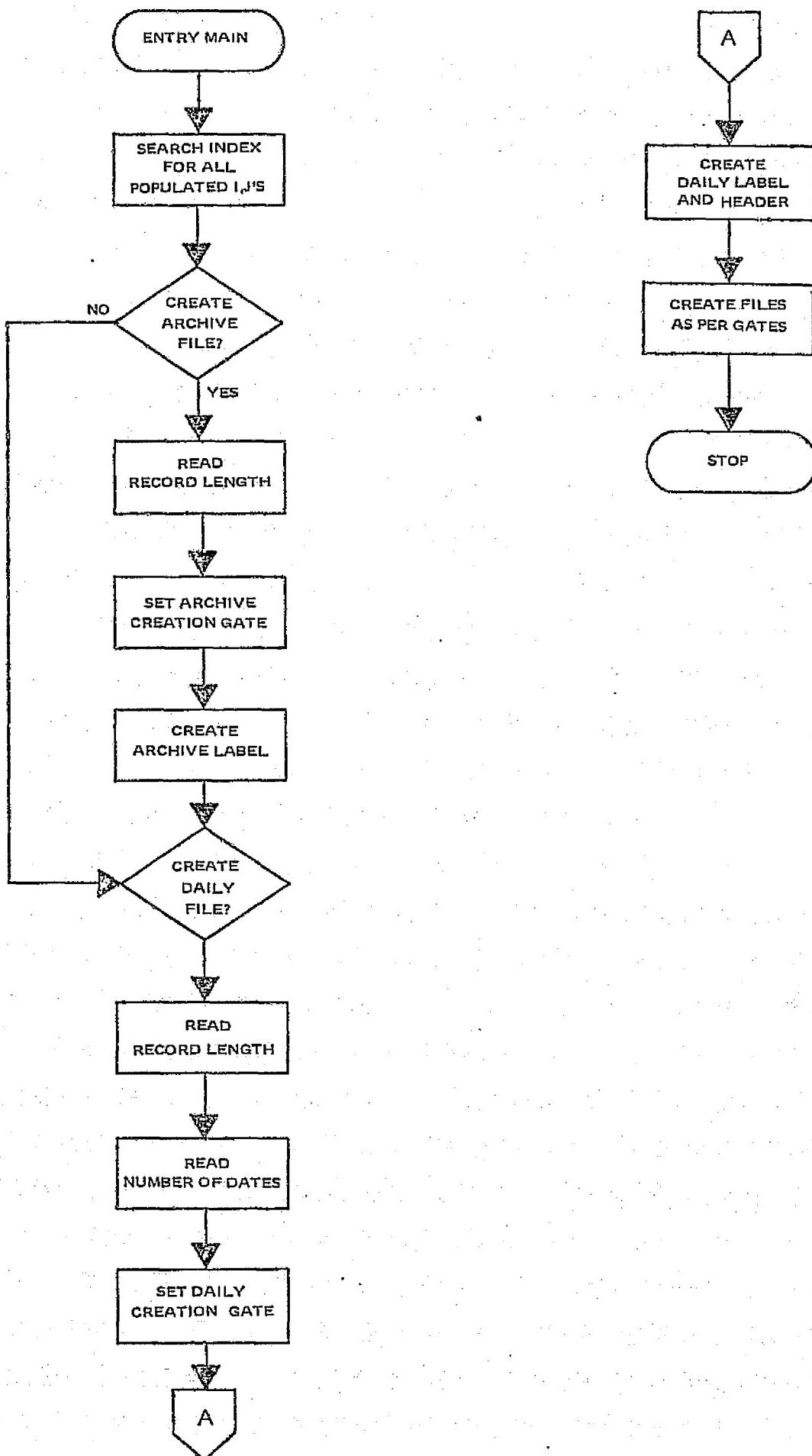
- a. FILE (18) - LOGICAL*I, stores ASCII file name
- b. LRECA - Archive record length
- c. IDEV - ASCII device name
- d. IUNT - Physical device number
- e. BUFF (40) - I/O buffer
- f. LRECD - Daily record length
- g. NDAT - Number of dates in daily file
- h. IMIN - Minimum I value
- i. JMIN - Minimum J value
- j. NUMI - Number of I values
- k. NUMJ - Number of J values
- l. B12 - Basin numbers for K equals one and two
- m. B34 - Basin numbers for K equals three and four
- n. NRECP - INTEGER*4, number of records in index file
- o. NRECD - INTEGER*4, number of records in daily file

- p. NRECA - INTEGER*4, number of records in archive file
- q. NWORDA - INTEGER*4, number of words in archive file
- r. NWORD - INTEGER*4, number of words in daily file
- s. NRECPD - INTEGER*4, number of records for each date in daily file
- t. RNUM - INTEGER*4, record number from index file

4.3.3 User's Guide

| <u>PROMPT</u> | <u>RESPONSE</u> |
|---------------------------|----------------------------------|
| DATA BASE NAME?> | Nine-character alphanumeric name |
| DEVICE NAME?> | Two-character device name |
| UNIT NUMBER?> | Integer number |
| CREATE ARCHIVE FILE?> | Y or N |
| ARCHIVE RECORD LENGTH | |
| (DOUBLE WORDS)?> | Integer number |
| CREATE DAILY FILE?> | Y or N |
| DAILY RECORD LENGTH | |
| (DOUBLE WORDS)?> | Integer number |
| NUMBER OF DATES DESIRED?> | Integer number (1-31) |

C DATA



4.4 NBASIN

NBASIN traverses both the archive and the daily file and inserts a direct access pointer in each record, which when added to the current record number will show the position of the next record within the same basin.

4.4.1 Common Areas

a. ARCHV

1. NRECA - INTEGER*4, number of records in archive file
2. A - INTEGER*4, associate variable for archive file
3. LUNA - Logical Unit Number for archive file
4. LRECA - Archive record length

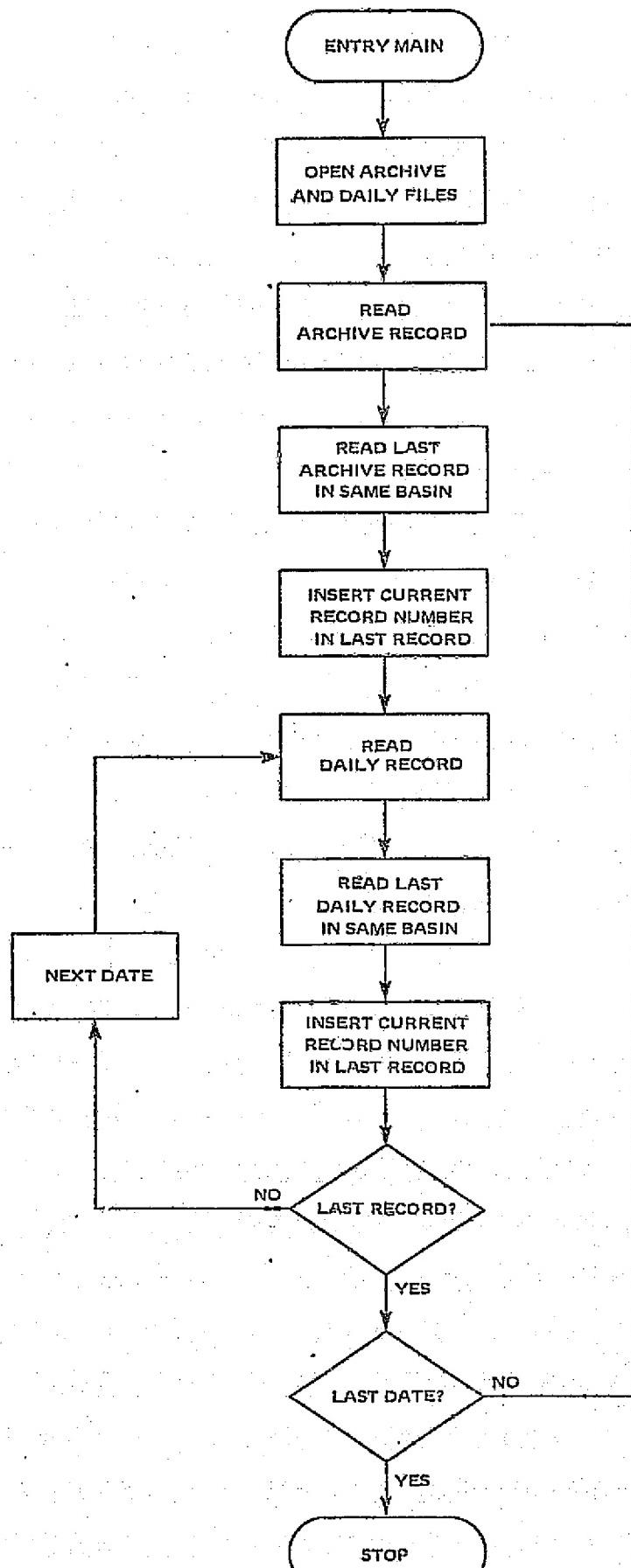
b. DAILY

1. NRECD - INTEGER*4, number of records in daily file
2. D - INTEGER*4, associate variable for daily file
3. NRECPD - INTEGER*4, number of records per date
4. LUND - Daily file Logical Unit Number
5. LRECD - Daily record length
6. NDATES - Number of dates in daily file
7. JDATE (31) - Julian dates contained in daily file

4.4.2 Variables

- a. LAST (10) - INTEGER*4, saves record number in which basin number (1-10) was last encountered
- b. NREC - INTEGER*4, current record number
- c. DREC - INTEGER*4, record number for key insertion
- d. BASIN - Basin number (ASCII)
- e. BNUM - Basin number in binary
- f. BUFF (40) - I/O buffer

NBASIN



4.5 OPENPT

OPENPT contains several entry points which open the data base file and process the file labels and header records. The four entry points are OPENB, OPENPT, OPENAR, and OPENDY. Each will be discussed separately.

4.5.1 OPENB

OPENB must be called once before any of the other modules are accessed. OPENB accepts a nine-character data base name to which it appends the type qualifier '.LBL'. The resulting file name points to the data base label file. OPENB also accepts a two-character device name and an integer physical unit number to completely specify the location of the data base. Subsequent calls to the other modules in this group will now refer to the data base defined in OPENB - this avoids the necessity of redefining the data base each time an individual member file (index, archive, or daily) is opened.

4.5.1.1 Argument List

None

4.5.1.2 Common Areas

None

4.5.1.3 Variables

- a. Label (18) - LOGICAL*1, array into which the label file may be misplaced

- b. LBL1 (4) - LOGICAL*1, array used to store the type qualifier 'LBL'
- c. IDEV - Two-character device name
- d. IUNT - Physical unit number

4.5.2 OPENPT

OPENPT opens the index file of the data base previously specified by OPENB on the Logical Unit Number LUN which is passed through the argument list. First, the label file is opened and the index file label is read. The label file contains the following information:

1. Number of records in file
2. Record length (words)
3. ASCII file name

The label file is then closed and the file specified in the label is opened for direct access I/O. The header record specifying the dimensions of the index file is read, and this information along with the first two entries in the label is passed to the calling program through a common block.

4.5.2.1 Argument List

- a. LUN - Logical Unit Number

4.5.2.2 Common Areas

- a. INDEX

- 1. NRECP - INTEGER*4, number of records in index file
- 2. P - INTEGER*4, associate variable for the index file
- 3. LUNI - Logical Unit Number

4. LRECP - Record length of index record
5. IMIN - First I value
6. NUMI - Number of I values
7. JMIN - First J value
8. NUMJ - Number of J values

4.5.2.3 Variables

- a. FILE (18) - LOGICAL*1, file name in ASCII

4.5.3 OPENAR

OPENAR opens the archive file of the data base in the same way that the index file is open. However, the archive header record is blank so header processing is not necessary.

4.5.3.1 Argument List

- a. LUN - Logical Unit Number

4.5.3.2 Common Areas

- a. ARCHV

1. NRECA - INTEGER*4, number of records in archive file
2. A - INTEGER*4, associate variable of archive file
3. LUNA - Logical Unit Number
4. LRECA - Archive record length

4.5.4 OPENDY

OPENDY opens the daily file of the data base in the same way that the index file is opened. The daily file header contains the following information:

1. Number of records for each date
2. Number of dates in file
3. Pointer into date array indicating last date entered
4. Array of dates contained in file

Along with the logical unit number, a Julian date is passed in the argument list. OPENDY searches for this date in the array of dates and if it is found, the file is positioned to the start of that date. If the date is not found, the program will determine if there is room for a new date or if an old date will have to be deleted. No date creation or overwriting will take place without operator approval. If an old date is overwritten, all data entries other than the I,J,K numbers and the basin number are erased and the new date is inserted both in the header record and in each data record within that date. Also, the pointer indicating the last date entered is updated.

4.5.4.1 Argument List

- a. LUN - Logical Unit Number to be opened
- b. DATE - INTEGER*4, Julian date to be found
(YYDDD)

4.5.4.2 Common Areas

a. DAILY

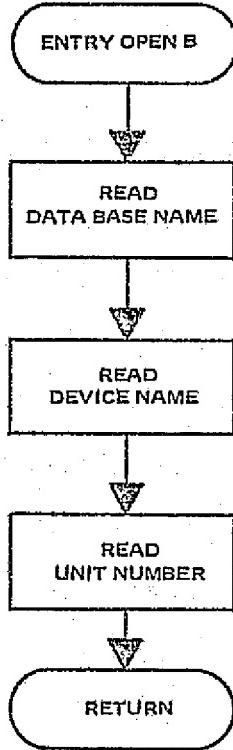
1. NRECD - INTEGER*4, number of records in file
2. D - INTEGER*4, associate variable of file
3. NRECPD - INTEGER*4, number of records per date

4. LUND - Logical Unit Number
5. LRECD - Record length (words)
6. NDATES - Number of dates in file
7. JDATE (31) - Julian dates (DDD) contained
in file

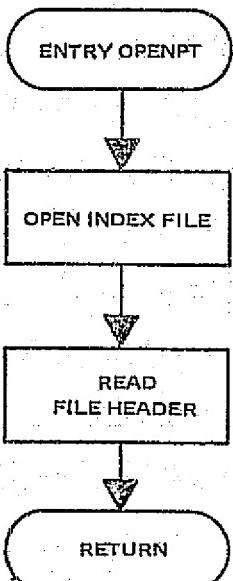
4.5.4.3 Variables

- a. FILE (18) - LOGICAL*I, daily file name
- b. IDATE - Julian date, not including year
- c. LAST - Points to last date entered in array
JDATe
- d. ADAT (3) - Target array used for coding
Julian date into six bytes ASCII equivalents
- e. BUFF (40) - I/O buffer

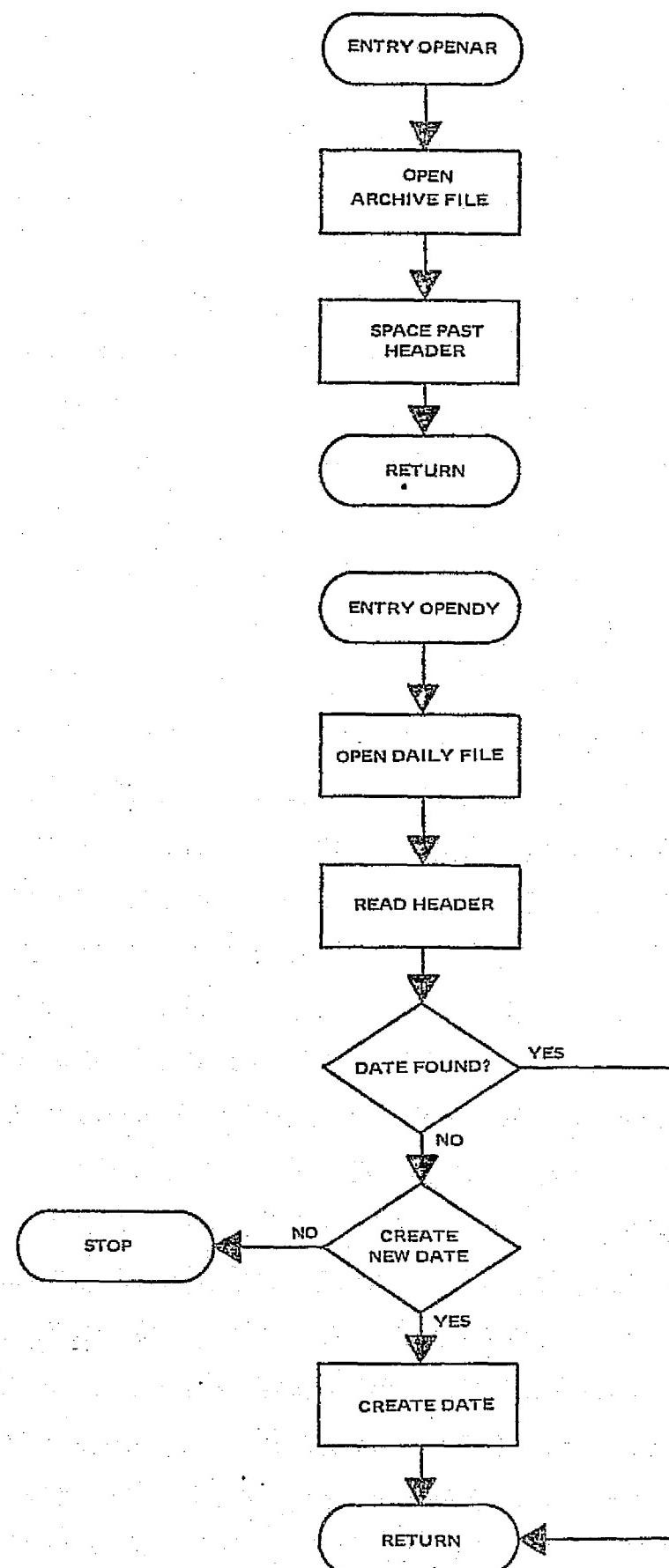
OPENPT



OPENPT



OPENPT



4.6 PLYDMP

PLYDMP is the first step in preparing SMS-derived data for insertion into the data base. It is currently set up for the processing of precipitation estimate derived from visible SMS images, but it is designed to easily accommodate extension to other data types.

The purpose of PLYDMP is to accept cloud polygon data (generated by POLYGO) from the theme planes of the Image-100 and converted to data which can be used by the data base. For precipitation estimate the operator is prompted for the image date, precipitation interval, number of cloud polygons and the cloud types and amounts in each polygon. Cloud types and amounts are converted to precipitation estimates in a simple one-line equation as follows:

$$P = K_1 \times C_1 + K_2 \times C_2 + K_3 \times C_3$$

where P is the estimated precipitation, K1, K2 and K3 are constants and C1, C2 and C3 are the percentage amounts of cumulonimbus, nimbo stratus and cumulous-congestus clouds respectively. As each estimate is derived the operator is given the opportunity to edit it with a new value or accept the estimate.

Next the user is requested to type in the ground control points obtained from METPAK when the image was generated. These are used to define an afyne transformation to effectively register the image to the data base.

After the image is registered the data is dumped to a disk file for processing on the 11/70. Three header records are generated. The first contains a user defined label, the Julian date, the number of polygons and the information type. This header has the same format for all

information types. The second header contains the afyne coefficients for registration. The third header varies with information type and for precipitation data it contains the estimated precipitation for each polygon. Following the headers are 512 lines of image data which have been extracted from the theme planes. Each line contains 512 bytes, one per pixel, with the value of each pixel corresponding to the polygon number of that pixel. Polygon numbers are the same as the theme numbers and must be consecutive starting at theme number one.

4.6.1 Common Areas

None.

4.6.2 Variables

- a. BUFF (256) - Output buffer for disk.
- b. MONTH (12) - Conversion table for Julian date.
- c. CAMT (3) - Cloud amount for types 1-3.
- d. TBUF (32) - Input buffer for themes.
- e. JDATE - INTEGER*4, Julian date.
- f. PCP (8) - REAL*4, Estimated precipitation for eight polygons.
- g. K (3) - REAL*4, K coefficients for precipitation estimation.
- h. XF - REAL*4, Precipitation interval.
- i. NPLY - Number of polygons.
- j. ITYP - Information type.

4.6.3 User's Guide

PLYPDMP is initiated by the MCR command RUN PLYDMP\$. The user will be requested to supply the following information:

PROMPT

RESPONSE

FILE NAME? >

File Name (1-33 characters)
for output file.

ENTER UP TO 34 CHARACTERS OF
IMAGE IDENTIFYING INFORMATION >

Self explanatory

NUMBER OF POLYGONS? >

Integer (1-8)

INFORMATION TYPE? >

Carriage return for a list
of types, one for precipitation.

IMAGE DATE? >

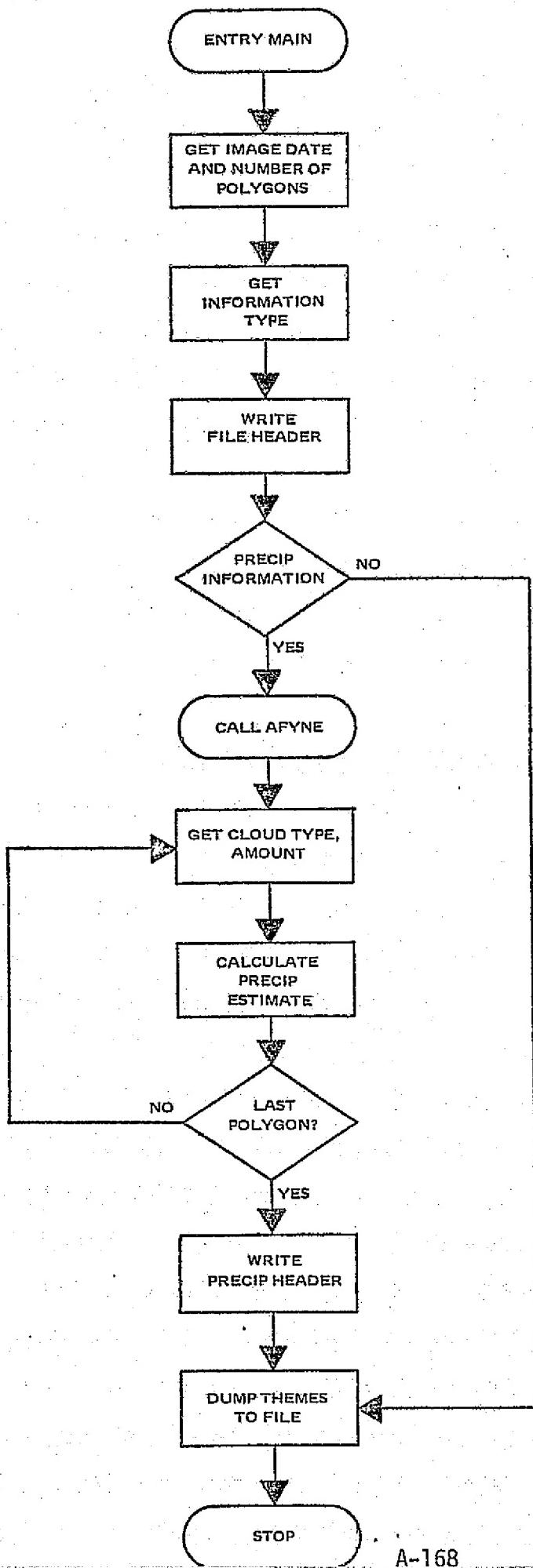
MN, DD, YY.

PRECIP INTERVAL (HOURS)? >

Integer (1-24).

CLOUDS TYPE, AMOUNT? >

Integer (1-7), Integer (1-100).



4.7 PLYRD

PLYRD is designed to process the polygon information which was previously generated by PLYDMP. It is presently able to process precipitation estimates only.

4.7.1 MAIN

First the polygon file is opened and the first header is read to determine the information type and the image date. Then the index file is opened and the daily file is opened to the dates specified in the polygon header. The second header is read to obtain the image registration data.

For precipitation data the third header is read and the precipitation estimates are transferred in ASCII in coded form to the array ADAT. ADAT is then passed to subroutine STASH which enters the data into the daily file.

4.7.1.1 Common Areas

a. PLYGN

1. DATE - INTEGER*4, Julian date.
2. LUN - Logical Unit Number.
3. NPLY - Number of polygons.
4. ITYP - Information type.

b. DBUF

1. BUFF (256) - Input buffer.

4.7.1.2 Variables

- a. ADAT (3,8) - Eight precipitation estimates in ASCII.
- b. NCHAR - Length of precipitation field in daily record.
- c. NSPACE - Position of precipitation field in daily record.

4.7.2 OPENPG

Subroutine OPENPG opens the polygon file and processes the first header record.

4.7.2.1 Argument List

None

4.7.2.2 Common Areas

- a. DAILY
 1. NRECD - INTEGER*4, Number of records in daily file.
 2. D - INTEGER*4, Associate variable of daily file.
 3. NRECPD - INTEGER*4, Number of records per date.
 4. LUND - Logical Unit Number.
 5. NDATES - Number of dates.
 6. JDATE (31) - Julian dates in file.
- b. PLYGN - See 4.7.1.1
- c. DBUF - See 4.7.1.1

4.7.2.3 Variables

- a. FILE (17) - Polygon file name.

4.7.3 STASH

Subroutine STASH reads the 512 lines of polygon data and inserts the correct precipitation estimates into all four K-cells for each I,J within each polygon. STASH can also be used to insert other parameters by changing NCHAR and NSPACE which define the field size and position within the daily file record.

After each line of data is read it is extended to one pixel per word format. The value of each pixel is checked to determine if it belongs to a polygon. If it does IJREG is called to get the I,J cell number of the pixel and the corresponding precipitation estimate is entered into each populated K-cell of that I,J.

4.7.3.1 Argument List

- a. ADAT (3,8) - Eight precipitation estimates in ASCII.
- b. NCHAR - Length of precipitation field in daily record.
- c. NSPACE - Position of precipitation field in daily record.

4.7.3.2 Common Areas

- a. INDEX

1. NRECP - INTEGER*4, Number of records in index file.

2. P - INTEGER*4, Associate variable of index file.
 3. LUNI - Index file Logical Unit Number.
 4. LRECP - Index record length.
 5. IMIN - Minimum I value.
 6. NUMI - Number of I values.
 7. JMIN - Minimum J value.
 8. NUMJ - Number of J values.
- b. PYLGN - See 4.7.1.1
 - c. DBUF - See 4.7.1.1
 - d. AFN
 1. V (3) - REAL*4, AFYNE coefficients, row 1.
 2. VV (3) - REAL*4, AFYNE coefficients, row 2.

4.7.3.3 Variables

- a. START - INTEGER*4, Start row number in daily file.
- b. BUFFD (40) - Buffer for daily file.
- c. BUFFW (512) - Expanded pixel buffer.

4.7.4 EXPAND

Subroutine EXPAND accepts a 512-byte buffer in the form of one pixel per byte and returns a 1024-byte buffer in the form of one pixel per word.

4.7.4.1 Argument List

- a. BUFFF (256) - Input buffer.
- b. BUFFW (512) - Output buffer.

4.7.5 IJREG

Subroutine IJREG accepts the row, column coordinates of an image pixel and returns the corresponding I,J cell numbers for that pixel. Registration is accomplished through an AFYNE transformation relating row column to latitude and longitude. The latitude and longitude can then be directly converted to the WMO grid coordinates.

4.7.5.1 Argument List

- a. X - REAL*4, Row coordinate.
- b. Y - REAL*4, Column coordinate.
- c. XI - REAL*4, I coordinate.
- d. XJ - REAL*4, J coordinate.

4.7.5.2 Common Areas

- a. AFN - See 4.7.3.2

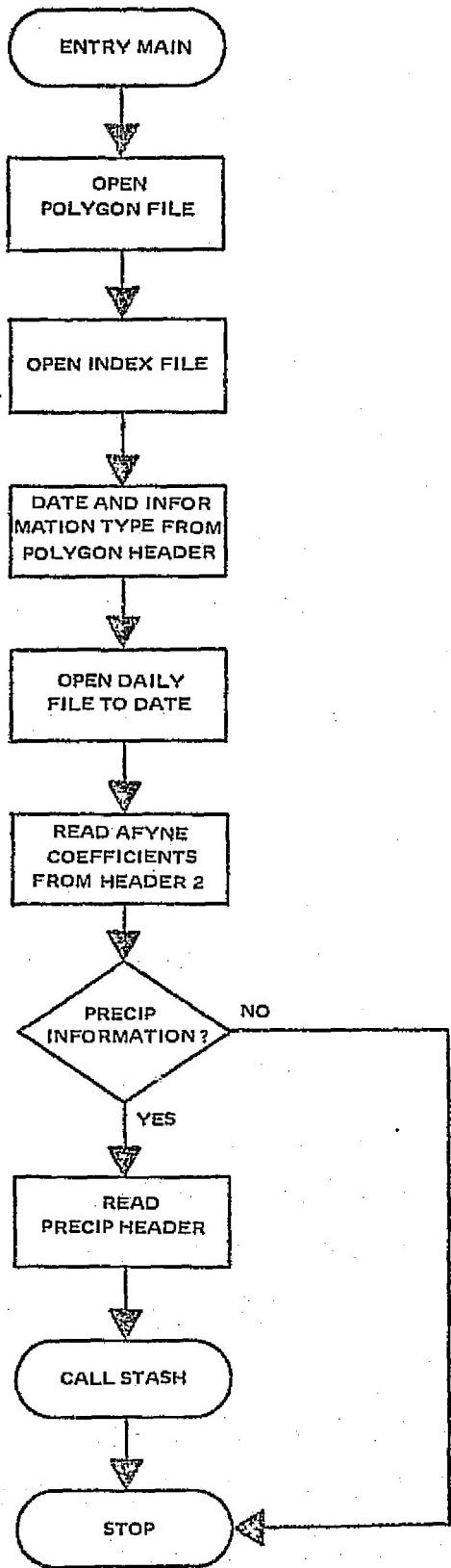
4.7.5.3 Variables

- a. XLAT - REAL*4, Latitude coordinate of pixel.
- b. XLON - REAL*4, Longitude coordinate of pixel.

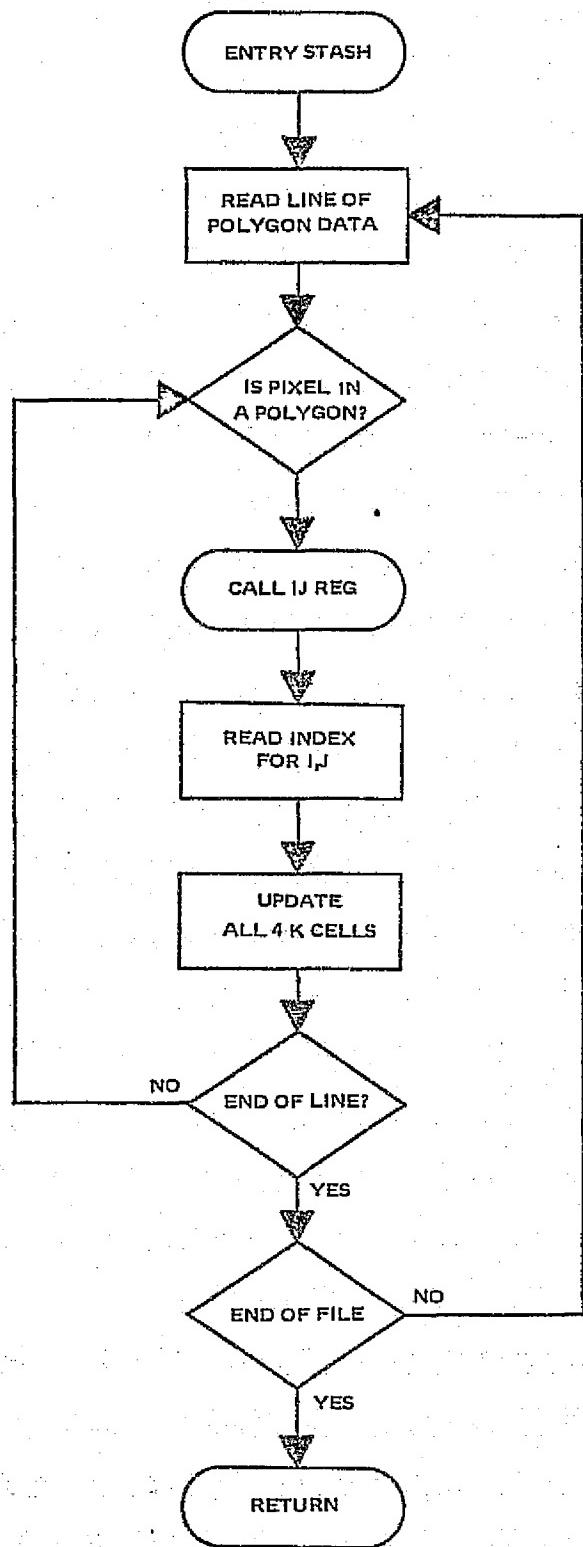
4.7.6 User's Guide

PLYRD is initiated by the MCR command RUN PLYRD\$. The user will be requested to supply the following information.

| <u>PROMPT</u> | <u>RESPONSE</u> |
|----------------------|-------------------------|
| DATA BASE NAME? > | 9-Character Name |
| DEVICE? > | 2-Character Device Name |
| UNIT NUMBER? > | 1-Digit Integer |
| POLYGON FILE NAME? > | 33-Character File Name |



STASH



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4.8 DISPLAY

DISPLAY provides a visual display of any of the data parameters stored in the data base. The display is in image format with constant J values along each row, constant I values along each column, and one pixel per K-cell.

4.8.1 MAIN

First the data base index file is opened and the user is prompted for file type (archive or daily). The data file is then open for input and the image file is open for output. The user is then prompted for information type and display limits. Only data entries which lie within the limits are displayed. Thus if the user wanted to display all K-cells with less than one inch of precipitation he would enter 0 as a display minimum and 1 as a maximum.

The output file is then built, two lines at a time, in subroutine EXTRACT if the parameter is integer, subroutine FLTEXT if the parameter is real.

4.8.1.1 Common Areas

- a. INDEX - See 4.5.2.2
- b. ARCHIVE - See 4.5.3.2
- c. DAILY - See 4.5.4.2

4.8.1.2 Variables

- a. BUFF (512,2) - Two output buffers.
- b. AOFF (10) - Archive record field positions.
- c. ASIZE (10) Archive record field sizes.

- d. DOFF (10) - Daily record field positions.
- e. DSIZE (10) - Daily record field sizes.
- f. AFLT (10) - For REAL parameters number of bytes after decimal point.
- g. DFLT (10) - For REAL parameters number of bytes after decimal point.

4.8.2 EXTRACT

Subroutine EXTRACT creates two lines of image data from a constant J row of the data base grid. The data can be extracted from either the archive or the daily files.

First the output buffers are cleared and the index file is searched for the first populated cell in the J row. If a populated cell is found the data file is positioned and processed until the J coordinate changes. For each K-cell in the row the data parameter is extracted and compared with the data limits. If the parameter lies within the limits, 255 is inserted in the corresponding output buffer position.

4.8.2.1 Argument List

- a. IFL - Flag, equals 0 for archive file equals 1 for daily file.
- b. OFFST - INTEGER*4, Number of records offset for a daily file.
- c. JNUM - J coordinate to be extracted.
- d. NSPACE - Position of data parameter.
- e. OUTBUF (512,2) - Output buffers.
- f. SIZE - Length of data parameter fields.

4.8.2.2 Common Areas

- a. MAXMIN
 - 1. MAX - Maximum data value
 - 2. MIN - Minimum data value
- b. INDEX - See 4.5.2.2
- c. DAILY - See 4.5.4.2
- d. ARCHIVE - See 4.5.3.2

4.8.2.3 Variables

- a. LUN - Data file Logical Unit Number
- b. LREC - Data file record length
- c. BYTES - Number of bytes to be decoded
- d. JLOC - INTEGER*4, Position of J row in index file
- e. RNUM - INTEGER*4, Record number of data file
- f. TEMP - Extracted data parameter

4.8.3 FLTEXT

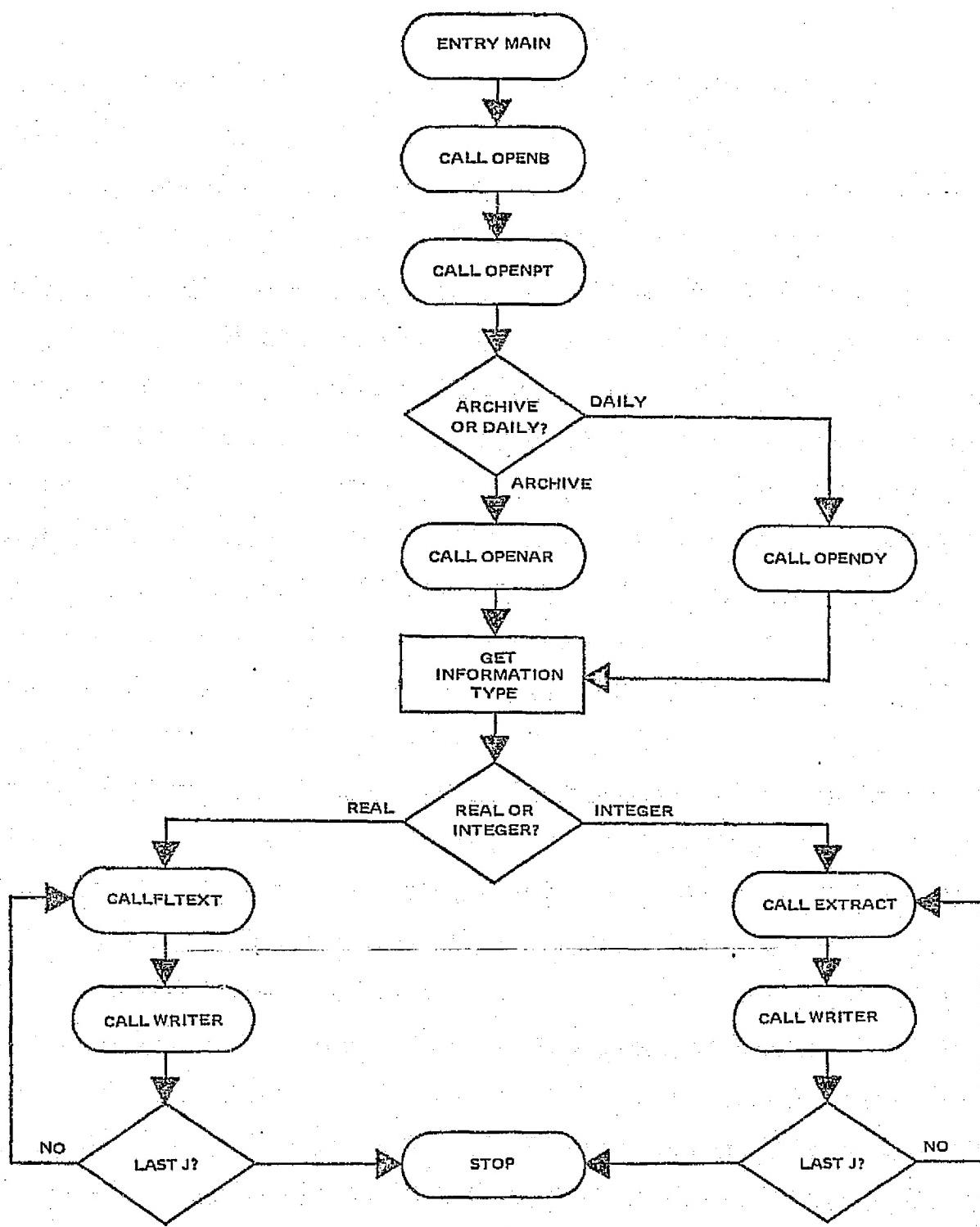
Subroutine FLTEXT is the functional equivalent of EXTRACT. Accepts that a floating point value rather than an integer is extracted from the data file.

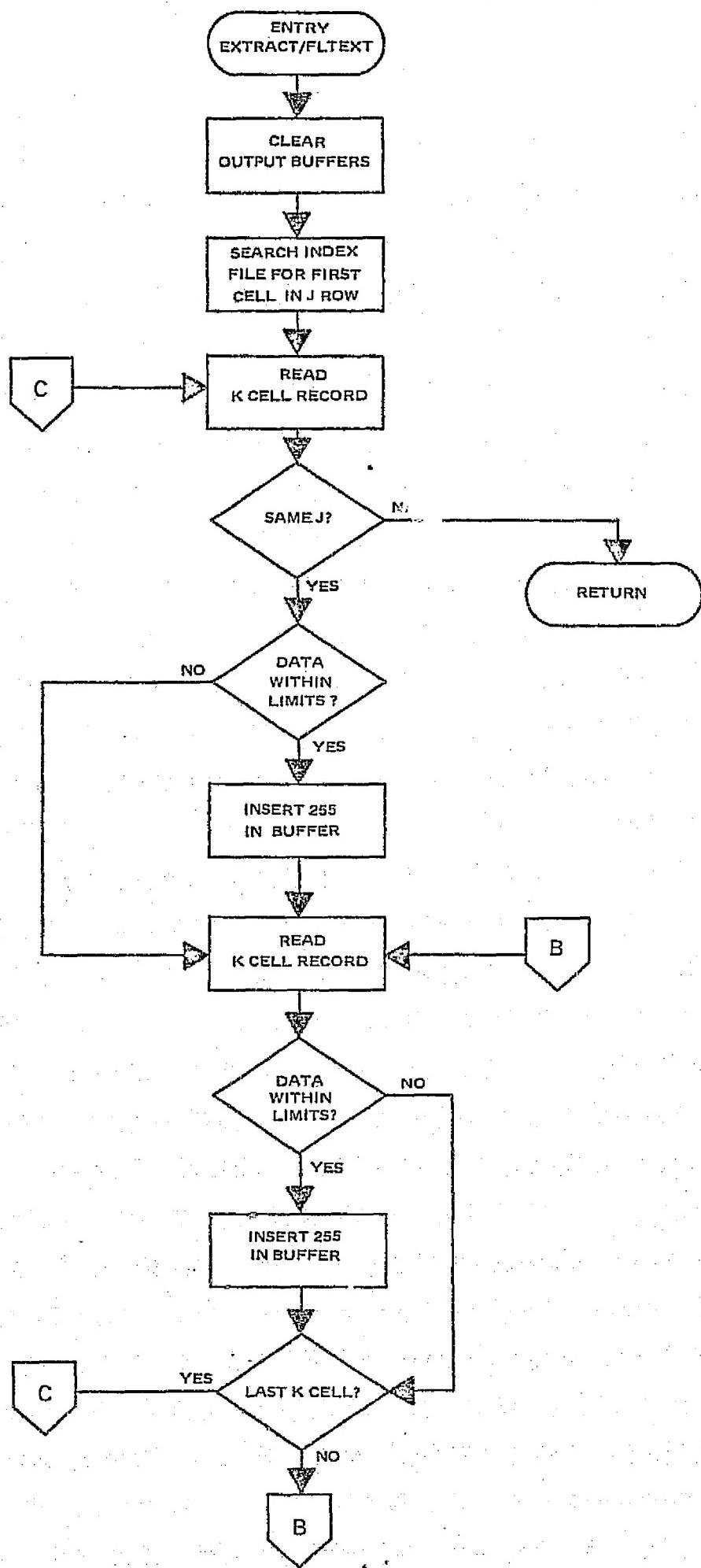
4.8.4 User's Guide

DISPLAY is initiated by the MCR command RUN DISPLAY\$. The user will be requested to supply the following information.

| <u>PROMPT</u> | <u>RESPONSE</u> |
|-----------------------------------|--|
| DATA BASE NAME? > | 9-Character Name. |
| DEVICE? > | 2-Character Device Name. |
| UNIT NUMBER > | 1-Digit Integer. |
| DISPLAY FROM ARCHIVE FOR DAILY? > | Self explanatory. |
| TYPE? > | Integer Number Selected From Display list. |
| MAXIMUM VALUE (INTEGER)? > | Self explanatory. |
| MINIMUM VALUE (INTEGER)? > | Self explanatory. |
| MAXIMUM VALUE (REAL)? > | Self explanatory. |
| MINIMUM VALUE (REAL)? > | Self explanatory. |

DISPLAY





4.9 ERTS 200

ERTS 200 is a multi-purpose task which allows the user to register an image to the WMO grid, produce a WMO grid overlay on a theme plane of the IMAGE-100, and aggregate LANDSAT classification data for insertion into the data base.

4.9.1 MAIN

The function of MAIN is to prompt the user for the desired option, insure the processing is being done in the correct order, and to call the required subroutines to do the processing. Before available options are REGISTER, OVERLAY, INSERT and STOP.

The REGISTER option calls subroutine AFYNE and allows the user to enter ground control points through the Image-100 cursor. The image is registered to the WMO grid through an AFYNE transformation. FLIP is called to define the reverse transformation. The REGISTER option must precede all other options.

The GRID option simply applies the transformation defined by the REGISTER option. The I and J limits of the desired window are determined by the subroutine LIMITS. Then the image coordinates are calculated for each I,J present in the window and a 3 x 3 cross is generated at the center of each cell.

The INSERT option utilizes the polygon routines to aggregate LANDSAT resolution data to the K-cell level. At present INSERT will accommodate the aggregation of ground cover classification only, but it may be easily expanded.

Finally the STOP option ceases all processing.

4.9.1.1 Common Areas

a. WDW

1. NROW - First row of window.
2. NROWS - Number of rows in window.
3. NCOL - First column of window.
4. NCOLS - Number of columns in window.
5. I1 - Minimum I value in window.
6. I2 - Maximum I value in window.
7. J1 - Minimum J value in window.
8. J2 - Maximum J value in window.

b. AFN

1. V (3) - REAL*4, AFYNE coefficients, image to LAT, LON, first row.
2. VV (3) - REAL*4, AFYNE coefficients, image to LAT, LON, second row.

c. BFN

1. Z (3) - REAL*4, AFYNE coefficients, LAT, LON to image, first row.
2. ZZ (3) - REAL*4, AFYNE coefficients, LAT, LON to image, second row.

4.9.1.2 Variables

- a. REGIST - Flag equals 1 if image has been registered, equals 0 otherwise.

4.9.2 AFYNE

Subroutine AFYNE allows the user to identify ground control points (GCP's) through the Image 100 cursor. The user is prompted

to enter the latitude and longitude of each ground control point.

The subroutine then performs a least squares fit to the ground control points to determine the best affine transformation relating the GCP's to latitude and longitude. The affine transformation is defined as:

$$\text{LAT} := A_1 I + B_1 J + C_1$$

$$\text{LONG} = A_2 I + B_2 J + C_2$$

where

LAT is the latitude of a particular GCP

LONG is the longitude of a particular GCP

I is the row index of the GCP

J is the column index of the GCP

Given N GCP's, define the following quantities;

$$\text{LAT} = \left\{ \begin{array}{c} \text{LAT}_1 \\ \text{LAT}_2 \\ \vdots \\ \text{LAT}_N \end{array} \right\} \quad \text{LONG} = \left\{ \begin{array}{c} \text{LONG}_1 \\ \text{LONG}_2 \\ \vdots \\ \text{LONG}_N \end{array} \right\}$$

$$A = \left\{ \begin{array}{ccc} I_1 & J_1 & 1 \\ I_2 & J_2 & 1 \\ \vdots & \vdots & \vdots \\ I_N & J_N & 1 \end{array} \right\}$$

$$C_{LAT} = \begin{Bmatrix} A_1 \\ B_1 \\ C_1 \end{Bmatrix}, \quad C_{LONG} = \begin{Bmatrix} A_2 \\ B_2 \\ C_2 \end{Bmatrix}$$

Then the coefficients of the affine transformation may be solved as follows;

$$\begin{aligned} LAT &= A C_{LAT} \rightarrow C_{LAT} = (\tilde{A} \tilde{A})^{-1} (\tilde{A} LAT) \\ LONG &= A C_{LONG} \rightarrow C_{LONG} = (\tilde{A} \tilde{A})^{-1} (\tilde{A} LONG) \end{aligned}$$

AFYNE uses subroutine MATINV to perform the matrix inversion.

4.9.2.1 Argument List

None

4.9.2.2 Common Area

- a. AFN - See 4.9.1.1

4.9.2.3 Variables

- a. V(3) - REAL*4, Temporary storage for vectors \tilde{A} LAT and \tilde{A} LONG
- b. VV(3) - REAL*4, Affine coefficients for latitude transformation
- c. VVV(3) - REAL*4, Affine coefficients for longitude transformation
- d. AA(20,3) - REAL*4, Storage for matrix A
- e. BB(3,3) - REAL*4, Storage for matrix $(\tilde{A} \tilde{A})^{-1}$

- f. CC(3,3) - REAL*4, Storage for matrix ($\tilde{A}A$)
- g. DD(3,3) - REAL*4, Not used
- h. ZI(20) - REAL*4, Storage for GCP row indices
- i. ZJ(20) - REAL*4, Storage for GCP column indices
- j. ZII(20) - REAL*4, Storage for GCP latitudes
- k. ZJJ(20) - REAL*4, Storage for GCP longitudes

4.9.3 GRID

Subroutine GRID generates a WMO grid overlay on a theme plane of the Image-100. GRID calls subroutine LIMITS to determine the maximum and minimum I and J coordinates grid window contained within the image window. Note that since the image window and grid window are skewed, not every I,J cell in the grid window is contained in the image window. However, the image window is wholly contained within the grid window.

Next a loop is entered in which each I,J coordinate is tested to determine if it is contained within the image window. If it is, a 3 x 3 cross centered on the I,J coordinate is generated on the desired theme plain.

4.9.3.1 Argument List

None

4.9.3.2 Common Areas

- a. WDW - See 4.9.1.1

4.9.3.3 Variables

- a. THEME - Output theme number.
- b. LIN1 - First line of cross.
- c. LIN2 - Last line of cross.

d. COL1 - First column of cross.

e. COL2 - Last column of cross.

4.9.4 AGGR

Subroutine AGGR aggregates LANDSAT classification data to the K cell level and inserts it into the data base. First it calls limits to get the image window coordinates (row, column) in the corresponding grid window coordinates (I,J). It then enters a loop which processes each I,J in the grid window. First it determines the intersection of the I,J cell and the image window. If the cell is contained in the watershed and is partially or completely contained within the image window, the cell vertices are passed to the polygon routines BORDER (Section 3.8.3), SORT (Section 3.8.4) and FILL200. These determine the interior points of the cell and return a histogram of the polygon data contained within the cell along with the total population of the cell. This information is converted to percentage of ground cover, encoded in ASCII and inserted in the corresponding record of the archive file.

4.9.4.1 Argument List

None

4.9.4.2 Common Areas

a. WDN - See 4.9.1.1

b. KCELL

1. K - K-cell number.

2. KHIST (8,4) - Polygon data histograms.

3. KNUM (4) - K-cell populations.

c. VTX

1. POINT (2,100,2) - K-cell border points.

2. NPT - Number of border points.

3. VERTEX (2,4) - K-cell vertices.
 4. NVTX - Number of vertices.
 5. LINK (5) - Pointers used by SORT.
- d. INDEX - See 4.5.2

4.9.4.3 Variables

- a. KI (4,4) - REAL*4, Table for calculation of K-cell vertices.
- b. KJ (4,4) - REAL*4, Table for calculation of K-cell vertices.
- c. PCT - REAL*4, Ground cover percentage.
- d. IPCT (8) - Ground cover percentage.
- e. ADAT (8) - Ground cover (ASCII).
- f. NSPACE - Position of ground cover field in archive record.
- g. NCHAR - Length of ground cover field in archive record.

4.9.5 LIMITS

Subroutine LIMITS prompts the user for the desired image window coordinates and calculates the grid window (I,J) which completely contains the image window. This is accomplished by calling IJREG (Section 4.7.5) to convert the image coordinates of the four image corners to their corresponding I,J coordinates. The maximum and minimum I and J values obtained by these four transformations define the bounds of the grid window.

4.9.5.1 Argument List

None

4.9.5.2 Common Areas

- a. WDW - See 4.9.1.1

4.9.5.3 Variables

- a. IMIN - REAL*4, Minimum I value.
- b. IMAX - REAL*4, Maximum I value.
- c. JMIN - REAL*4, Minimum J value.
- d. JMAX - REAL*4, Maximum J value.

4.9.6 FLIP

Subroutine FLIP accepts six AFYNE transformation coefficients and inverts them to define the reverse transformation.

4.9.6.1 Argument List

- a. V (3) - REAL*4, Input coefficients, first row.
- b. VV (3) - REAL*4, Input coefficients, second row.
- c. Z (3) - REAL*4, Inverted coefficients, first row.
- d. ZZ (3) - REAL*4, Inverted coefficients, second row.

4.9.7 XYREG

Subroutine XYREG accepts the grid coordinates (I,J) of a pixel and converts them to image coordinates (row, column). First

the I,J coordinates are converted to latitude and longitude which is then converted to row and column by an AFYNE transformation.

4.9.7.1 Argument List

- a. XI - REAL*4, I coordinates.
- b. XJ - REAL*4, J coordinates.
- c. X - REAL*4, Calculated row coordinate.
- d. Y - REAL*4, Calculated column coordinate.

4.9.7.2 Common Areas

- a. BFN - See 4.9.1.1

4.9.7.3 Variables

- a. XLAT - REAL*4, Calculated latitude.
- b. XLON - REAL*4, Calculated longitude.

4.9.8 FILL 200

Subroutine FILL 200 is a functional equivalent of FILLIN as described in Section 3.8.5. They differ only in that FILL 200 calls INS 200 which aggregates theme data rather than INSERT which builds an output buffer to be written to a theme.

4.9.9 INS200

Subroutine INS200 is called by FILL200 to aggregate a histogram of the K cell polygon data. It accepts a start column, end column and a row number and returns a histogram of the pixels contained within those limits.

4.9.10 MATINV

Subroutine MATINV uses a gaussian elimination with pivoting procedure to perform a matrix inversion.

4.9.10.1 Argument List

- a. N - Order of matrix (maximum of three)
- b. A(3,3) - REAL*4, On entry, matrix to be inverted;
on return, matrix inverse
- c. ISING - Matrix return flag;
0 - non-singular
1 - singular

4.9.10.2 Common Areas

None

4.9.10.3 Variables

- a. LIST(3) - Row interchange record
- b. DETR - REAL*4, Determinant of matrix

4.9.11 User's Guide

ERTS200 is initiated by the MCR command RUN ERTS200\$. The user will be requested to supply the following information.

PROMPT

OPTION? >

for REGISTER option

IMAGE X, Y? >

LAT, LON? >

for OVERLAY option

OUTPUT THEME? >

for OVERLAY and INSERT options

FIRST LINE? >

NUMBER OF LINES? >

FIRST COLUMN? >

NUMBER OF COLUMNS? >

RESPONSE

Register, Overlay,
Insert or Stop

Enter column, Row of G.C.P.
or position cursor and press
C.R.. Enter X to exit

Enter Latitude, Longitude of
G.C.P. (2F12.4)

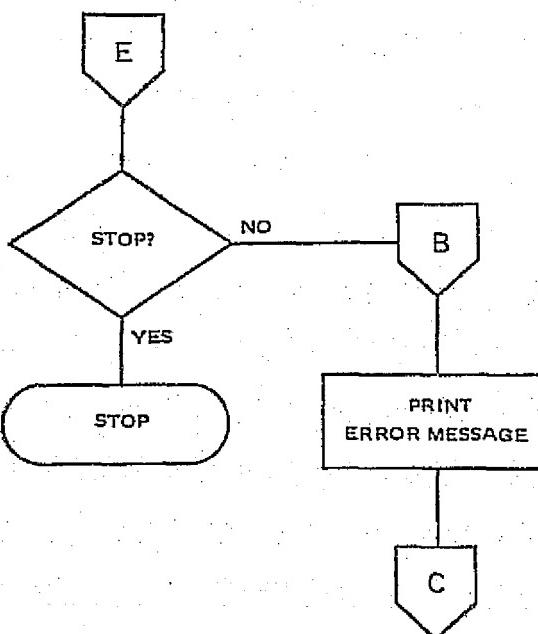
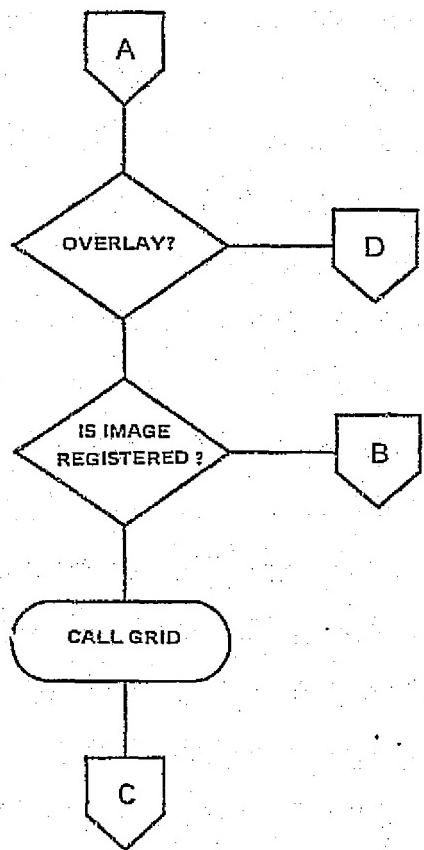
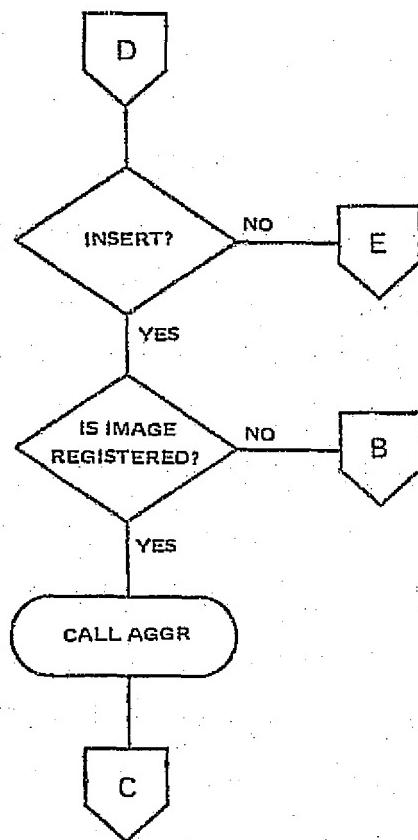
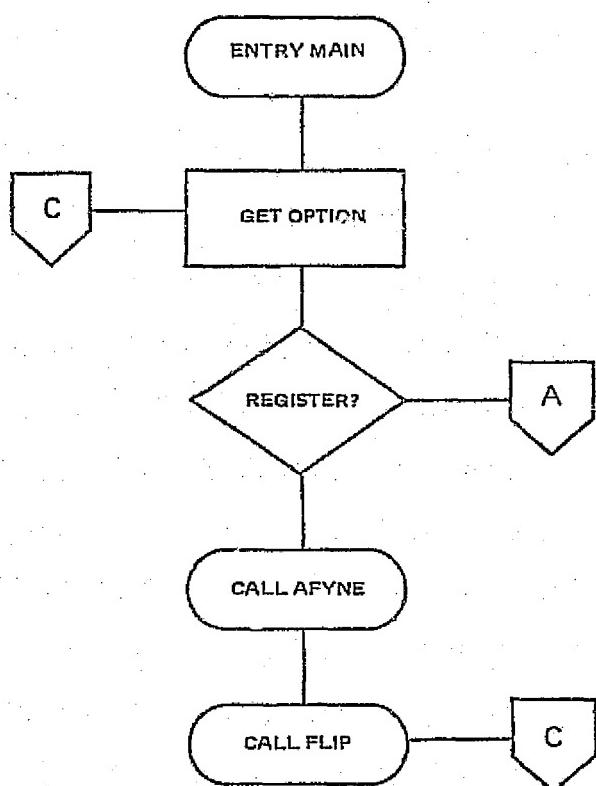
Integer (1-8)

Positive integer

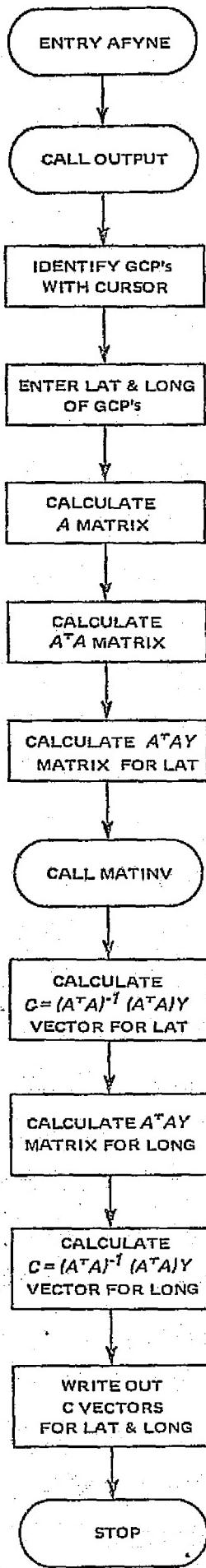
Positive integer

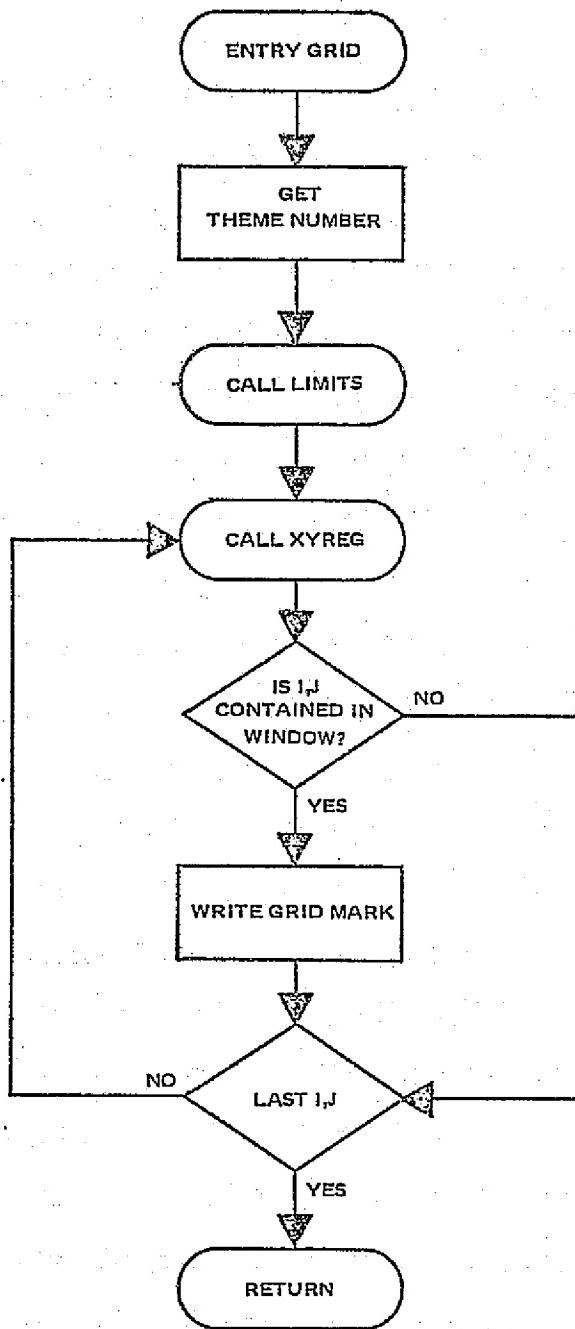
Positive integer

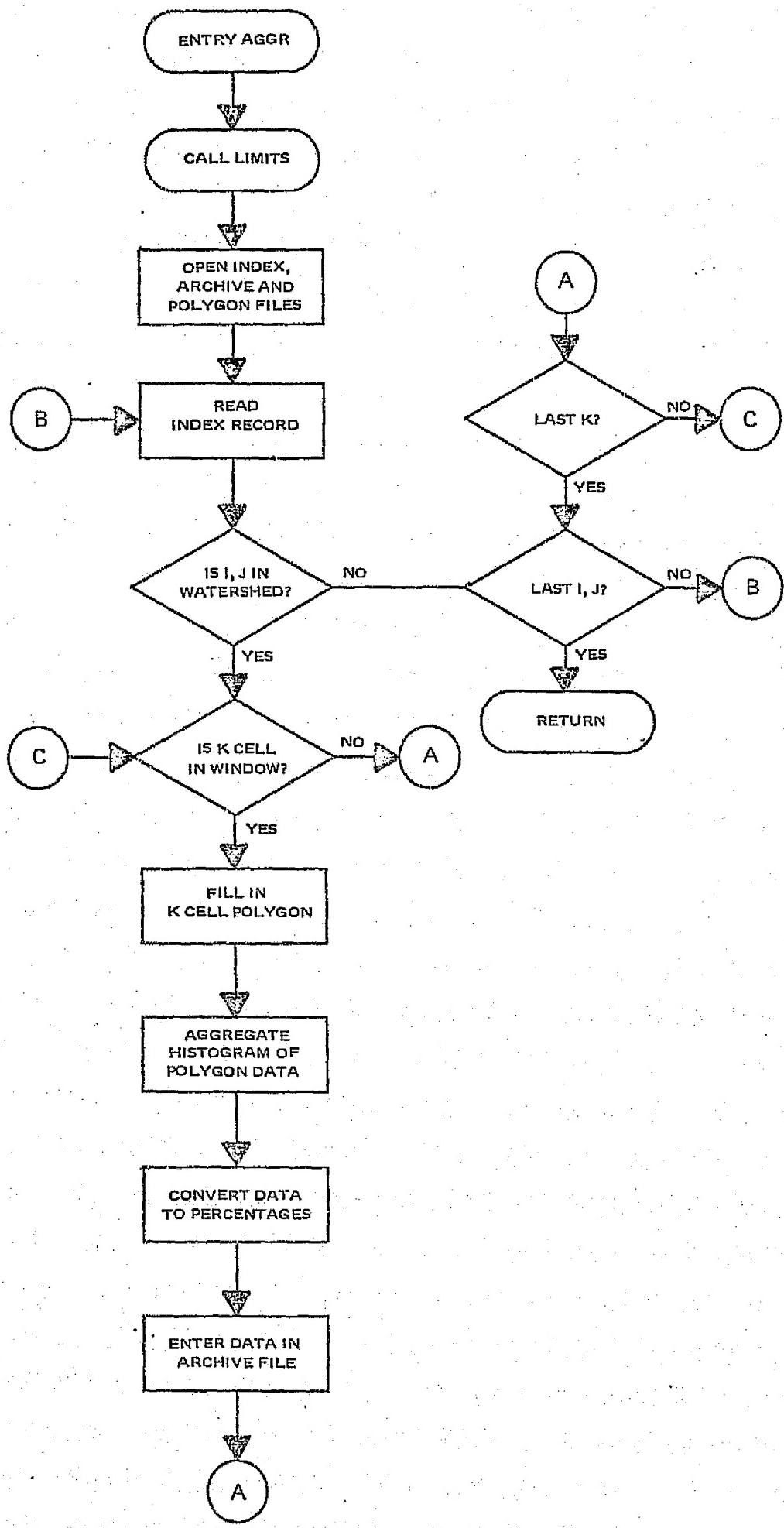
Positive integer

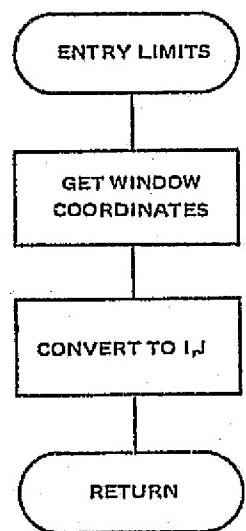


AFYNE

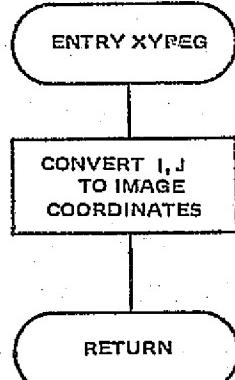




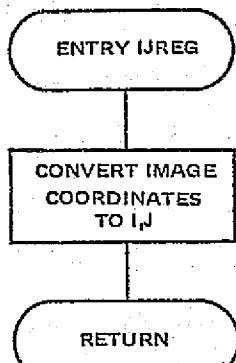




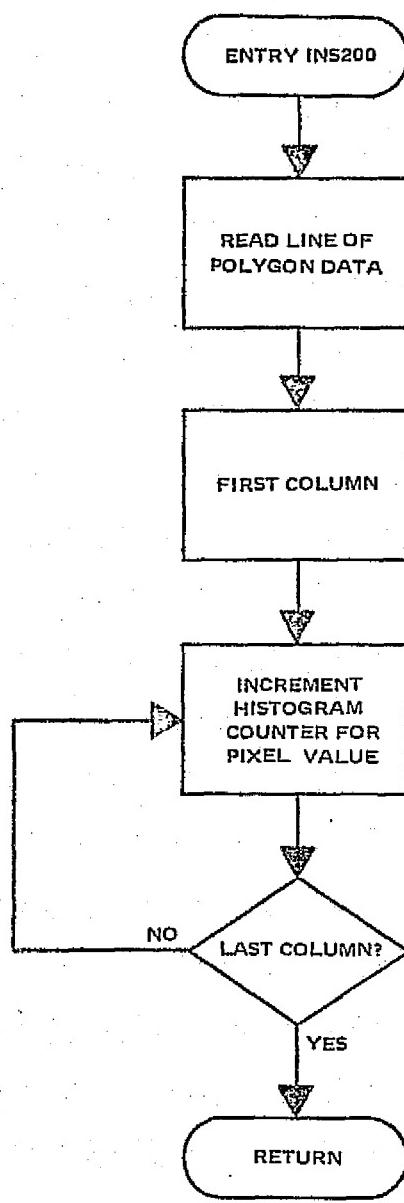
XYREG



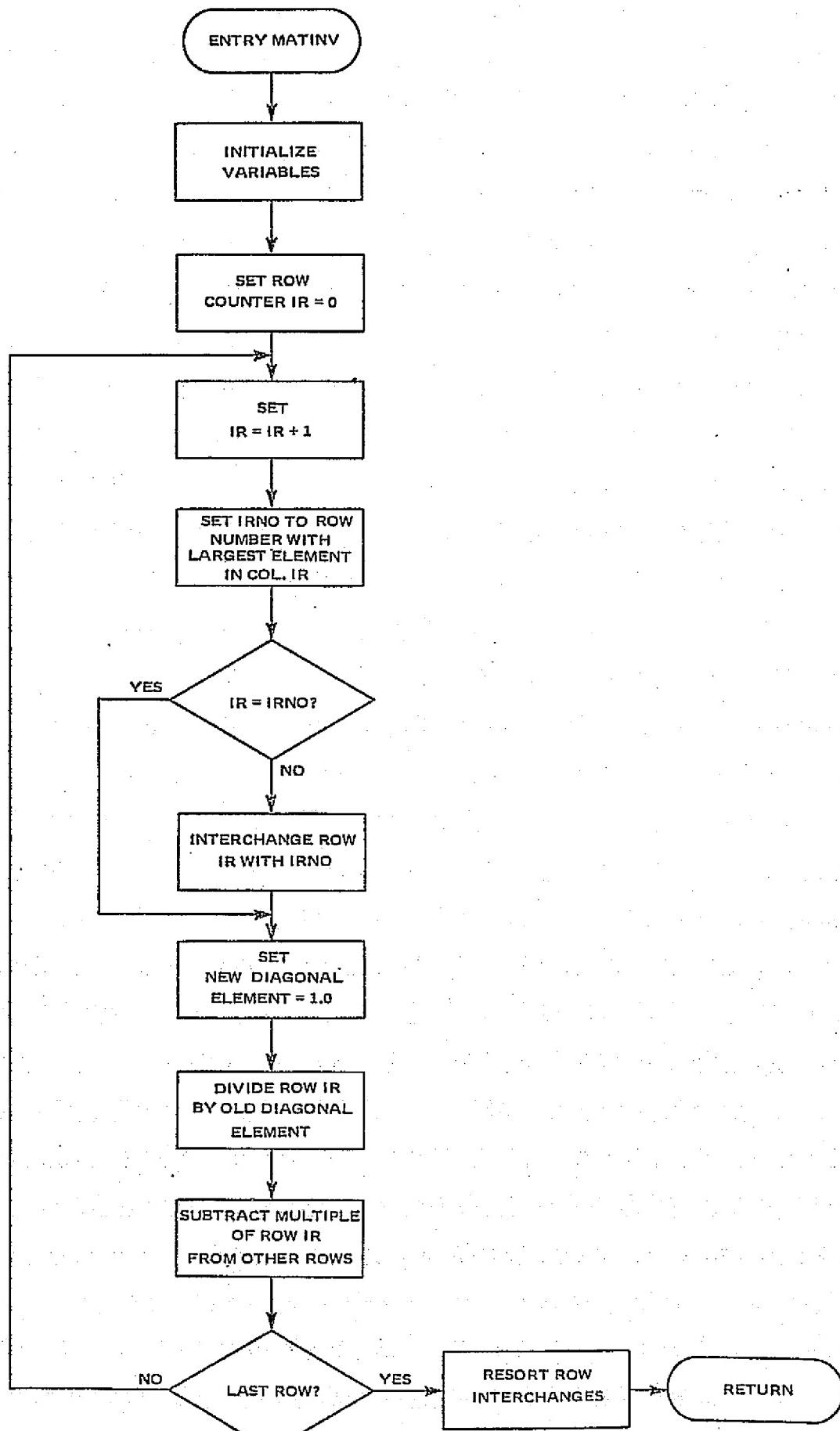
IJREG



INS200



MATINV



APPENDIX B

The 1980 Hydrologic Forecast situation: Where the major deficiencies will exist and how they may be improved.

SUMMARY

In the 1980's the demand for water will have risen considerably over the present levels in the conterminous United States. This demand will be felt most extensively in the urban areas of the western states. How will this demand be met by the 1980 state-of-the-art technology, and where are the likely deficiencies in the forecasting procedures going to occur? As can be best inferred from informative sources active in water resource management, the water forecasting procedure will rely heavily on data relay by ground, aircraft or satellite based transmission devices for more timely and reliable point source measurements of the naturally occurring phenomena related to river discharge. Localized automatic data receiving and processing centers will be in widespread use by such agencies as USGS, Department of Agriculture and others, for rapid centralized interpretation of conditions not only in one basin, but on the regional level in many parts of the country, thus providing a larger data base from which to more accurately forecast local conditions.

Although we may expect greater use and refinement of ground based telemetered data from point source measurements, a significant barrier to reduction of the forecast error will still remain. The barrier will be the obtaining of timely data on areal distributions of such water budget variables as soil moisture, evapotranspiration and snow water equivalence. Addendant meteorologic surrogate information including wind speed, net radiation, humidity, temperature and other parameters can presently be

measured either directly or indirectly, but the relationship of their aerial distribution to the real water balance of a basin is yet to be defined and applied to the actual basin-wide forecasting activity on an operational basis.

In brief, 1980 forecasting procedures will rely on technologically advanced methods of identifying, more accurately and rapidly, the hydrologic conditions at sample points throughout the basin in question. However, because the limitations to reduction in the forecast error beyond this level are inherent in the limitations of the point source sampling procedure, the major contributions to forecast improvement by 1980 will be those techniques which allow interactive operations and employ direct or surrogate measurements of the areal extent of the actual phenomena in question.

INTRODUCTION

The attempt of this paper is to relate the forecast deficiencies in the 1980's. This subject implies many facets, each of which could occupy the bulk of the report alone. Within the time allotted, only the more important topics are discussed, each of which builds upon the predecessor to provide a foundation for the projections. What follows then, is a discussion of current forecast techniques, the current forecast errors, and future forecast techniques and expected errors. Prerequisite to an understanding of the rationale behind a hydrologic forecast is an understanding of the hydrologic cycle: the process which defines the flow of water in the earth and atmosphere.

THE CYCLE

In the hydrologic cycle, water evaporates from the oceans and the land and becomes a part of the atmosphere. The evaporated moisture is lifted and carried in the atmosphere until it precipitates to the earth, either on land or in the oceans. Precipitated water may be intercepted or transpired by plants, may run over the ground surface and into streams and oceans, or may infiltrate into the ground. Much of the intercepted and transpired water and some of the surface runoff returns to the air through evaporation and transpiration. The infiltrated water may percolate downward to be temporarily stored as groundwater which later flows out of rocks as springs, or seeps into streams as runoff to oceans, or evaporates into the atmosphere to complete the cycle. Thus, the flow of water through the hydrologic cycle undergoes various complicated processes of evaporation, precipitation, interception, transpiration, infiltration, percolation, storage, and runoff. Figure B-1 illustrates this flow.

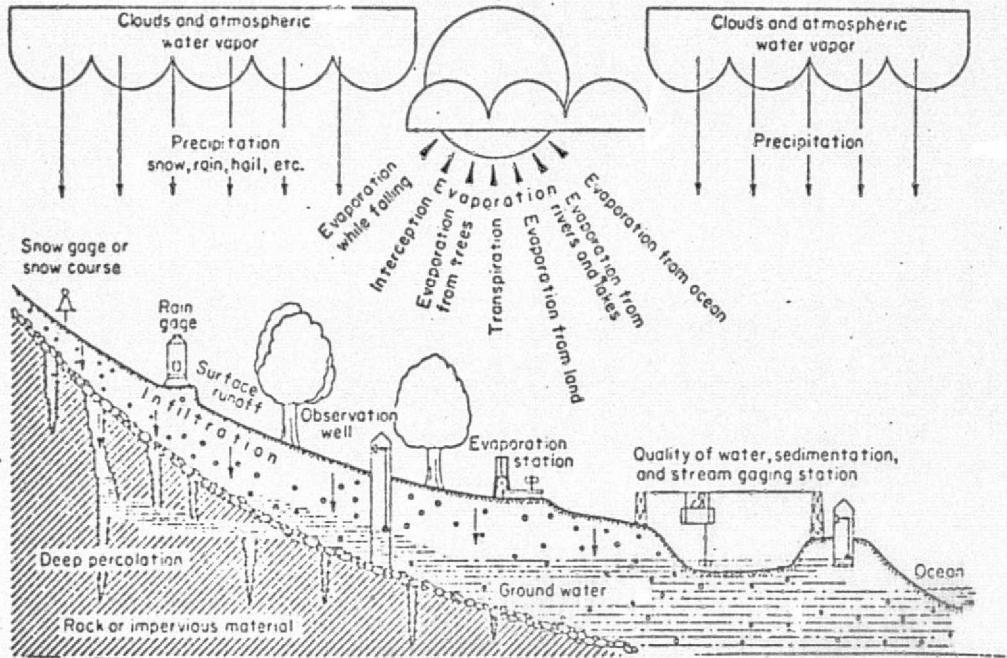


FIGURE B-1

Diagrammatic representation of the hydrologic cycle. (Adapted from ASCE Hydrology Handbook, 1949). Source: Walton. W. C. Ground Water Resource Evaluations, McGraw-Hill, Inc., N. Y. p. 4.

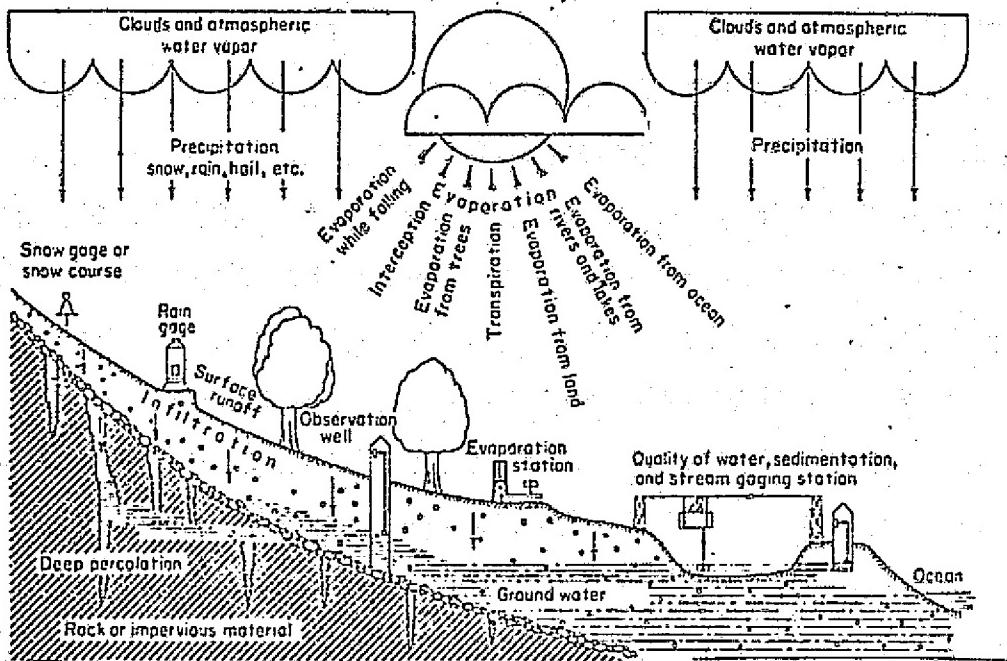


FIGURE B-1

Diagrammatic representation of the hydrologic cycle. (Adapted from ASCE Hydrology Handbook, 1949). Source: Walton. W. C. Ground Water Resource Evaluations, McGraw-Hill, Inc., N. Y. p. 4.

The amounts of evaporation, precipitation, runoff and other hydrologic cycle quantities are not evenly distributed on the earth, either geographically or temporally. In the conterminous United States, annual rainfall averages 1,430 cubic miles; evaporation is about 1,000 cubic miles; and about 40 cubic miles of water is discharged directly into the oceans from groundwater reservoirs. Several times 40 cubic miles of water passes through inland groundwater reservoirs and reaches stream channels to be discharged to the ocean via surface streams.

CURRENT FORECASTS

In the United States, two general forecasts of runoff are used depending on the requirements of the user. These are either forecasts of short term runoff including hourly, daily and seasonal predictions for flood warning or hydropower applications, or forecasts of annual runoff for recreation irrigation, hydropower, water supply and other uses. These forecasts may or may not depend on snow melt information depending on the geographic area in which the forecast is made.

CURRENT FORECAST PROCEDURES

Current forecasting procedures mostly utilize a wide variety of point source measurements of the phenomena (as was illustrated in Figure B-1, and combine these data with historical data in a regression equation to generate a forecast. A variety of computer programs have been developed to more accurately predict runoff by simulating the hydrologic cycle. However, the accuracy of the computer generated forecast is limited by the accuracy and representativeness of the input point source measurements. A subsequent discussion of modeling procedures will identify how the components of the hydrologic cycle are assembled

for forecast purposes. More appropriate at present is the evaluation of point source measurement limitations.

Illustrative of the limiting effect of point source measurements is the effect of an increasing number of raingauges on actual reduction in average error of measurement. In the following network chart (Figure B-2) it can be demonstrated that for any particular basin of known storm rainfall amounts and average annual precipitation, a non-linear progression of the increases of gauges (point source measurements) is required to bring about a uniform reduction in error. In other words, the addition of more point source measurements reaches a point of diminishing returns with respect to the decrease in error related.

ERRORS IN FORECASTING

The above point becomes salient in consideration of the fact that the west wide normal error in forecasting is on the order of 18 percent ranging from 7 to 40 percent.^{2/} The remaining national forecast error is less than this figure with less variation. As will be related, the 1980 water allocation demand will require significant improvement in the current forecast error particularly in the southwestern states. Particular error distributions for various western regions are shown in Table 1 to pinpoint the geographic distribution. Of interest in this distribution is the fact that the areas of higher forecast errors are in general expected to receive the major influx of future population expansion.

Another factor to consider in the current forecast procedures is that of the range and distribution of error in measurement of the individual variables of the water budget. Of these variables the majority

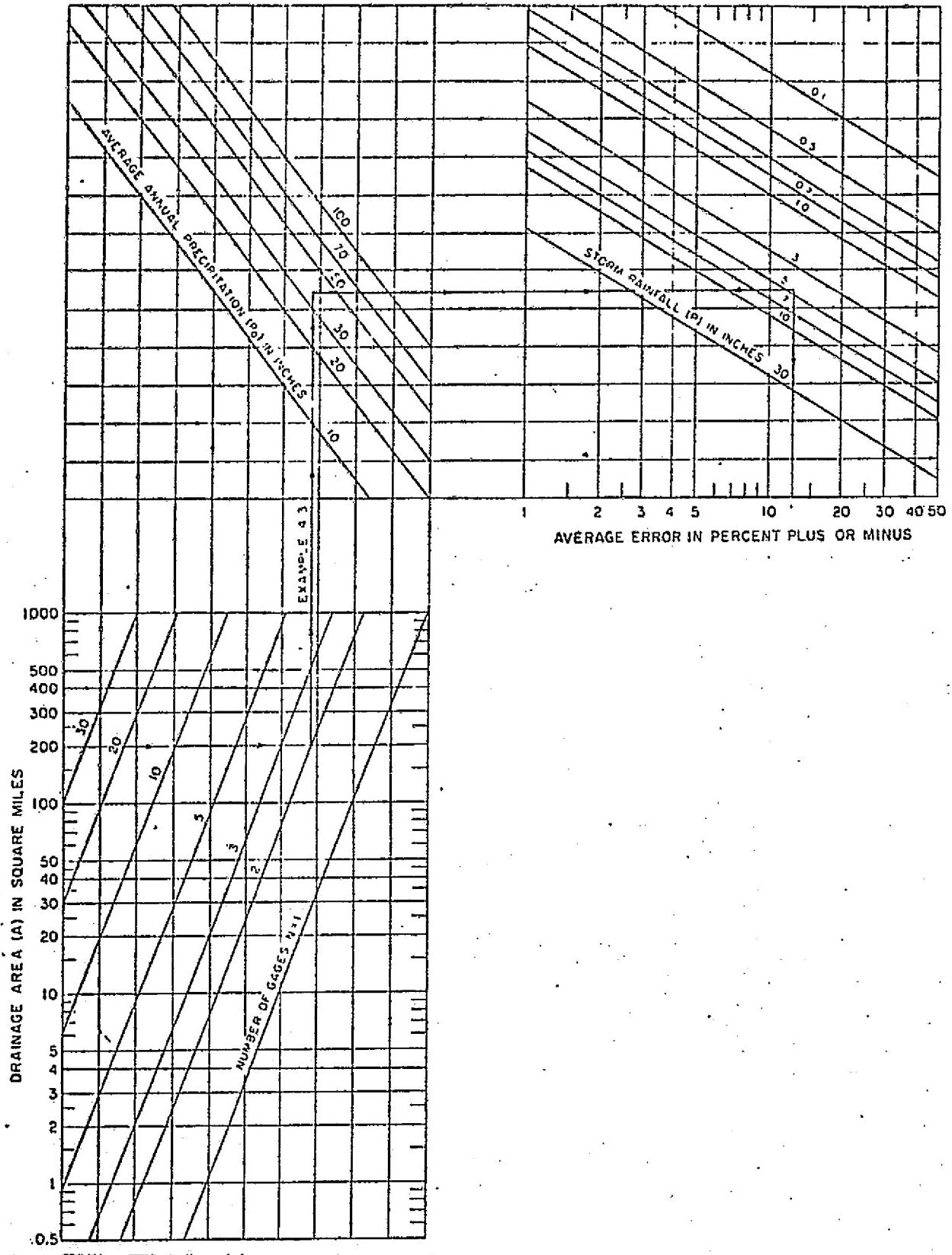


FIGURE B-2

Network chart for estimating the error in watershed average rainfall amounts.
 Source: Soil Conservation Service "Hydrology", Section 4 of National Engineering Handbook, 1969, p.4-20.

of water budget calculations over the whole United States suggests that evapotranspiration and soil moisture are the two major unknowns in the general runoff forecast. According to a credible source:

"Most programs for basic data cover precipitation, streamflow, evapotranspiration, ground water occurrence and other phases of the water cycle we already know about. The recommendations generally made for additional water data include very little pertaining to infiltration, soil moisture, and evapotranspiration which constitute the soil water phases of the water cycle. So little is actually known about these phases that even the listing of the national needs for additional data is a formidable task as is determining how their lack ^{3/} effects the national economy."

Particular interest might be centered on evapotranspiration because of its often dominant and unpredictable effect on the water budget. Commonly, evapotranspiration is estimated to amount to about 33 percent of runoff by mere rule of thumb because of a lack of field data and procedures by which more accurate measurements can be made. (This figure may range up to 60 percent in the arid southwestern United States.) ^{4/}

Field calculations of evapotranspiration generally rely upon extrapolation from point source measurements of evaporation, with corrections made to account for water losses due to transpiration from vegetation. More direct point source measurement of evapotranspiration is accomplished by

Forecast Error Distribution

| <u>Region</u> | <u>Av. Error*%</u> | <u>Sub-Region</u> | <u>Av. Error*(%)</u> |
|--------------------------------------|--------------------|---|------------------------------|
| California South Pacific | 10.0 | Tulare San Joaquin River Delta Central Sierra Sacramento | 10.0 10.0 10.0 |
| Columbia North Pacific | 10.2 | Clark Fork Kootenai Spokane | |
| "Upper Columbia" | 7.7 | Upper Columbia Yakima Upper Snake | 7.7 11.2 17.2 |
| "Snake" | 17.2 | Central Snake | 21.0 |
| "Lower Columbia" | 16.6 | Mid Columbia Lower Columbia Puget Sound | 16.6 12 |
| North Pacific Coastal Great Basin | 18.4 22.9 | Coastal Bear River Great Salt Lake Sevier Lake Central Lakoutian Humbolt River | 21 21 10 40 |
| Colorado | 26 | Upper Colorado Green River San Juan Colorado Little Colorado Salt Verde-Gila | 14 17 17 27 37.5 |
| Rio Grande | 29.1 | Upper Rio Grande Upper Pecos | 15.2 |
| Arkansas | 37.1 | | 37.1 |
| Missouri | 18.1 | Upper Missouri Yellowstone Platte Nebraska | 17.1 19 |

* Average Error is that error derived from the most recent 10 years record for the April 1 forecast. Where recent data was unavailable, error data was taken from less recent and more extensive periods of time.

Source: Unpublished West-wide Summary of SCS Forecast Error. SCS, Spokane, Washington.

TABLE - B-1

Forecast Error Distribution According to Geographic Location

use of a lysimeter, but due to the expense of this device, it is used only in a few of the more well funded research stations of the Department of Agriculture.^{5/}

In actual basins which are hydrologically better defined in terms of having more extensive gauges, uniformity of climatology, greater length of data recorded, etc., evapotranspiration may be derived through a water balance accounting. Using this procedure, the net losses in the hydrologic cycle (which are otherwise unaccounted for) are assigned to evapotranspiration. This subtractive process is limited by the accuracy of other measurements in the water cycle. A final method of generating evapotranspiration, used singularly or (more often) in conjunction with the other methods, entails the measurement of humidity, wind speed and temperature in an energy balance accounting to derive the evapotranspiration data. This method, used alone is rarely accurate because it fails to take into account available soil moisture in the basin and other unique basin characteristics which contribute to the actual evapotranspiration.

Like evapotranspiration, soil moisture may be derived from point source measurements. Soil moisture may also be computed on the basis of other inputs to the forecast. Its role in the total water budget is generally less dominant than evapotranspiration. Because the measurement of soil moisture is obtained by logic similar to that used in evapotranspiration. The discussion of measurement techniques will be bypassed here. Suffice it to state, however, that soil moisture is closer to being accurately quantified than evapotranspiration because of its more direct relationship to observable phenomena including soil type and extent.

Snow water equivalence data is currently derived by a combination of point source measurements of snow thickness and density which are multiplied by areal extent measurements to derive total water content of the snowpack. The point source measurements of snow density are made either by ground based surveys or low flying aircraft using transmitted gamma radiation measurements from ground based recording stations. Areal extent measurements, in themselves, are well defined and accurate relative to the snow depth/density measurements. Hence, the major problem posed by determination of total snow water equivalence is limited largely by the accuracy of snow depth/density measurements over a given areal extent of snow. The measurement of snow water equivalence applies mostly to the mountainous western basins in which snow derived runoff comprises a substantial percentage of the total precipitation.

FORECAST RESEARCH ACTIVITY

A brief look at presently funded research and operational activity of the larger government organizations suggests what is being done to reduce the forecast errors. Accordingly, the function and research activity of each of the major agencies concerned with hydrologic forecasts is capsulized in Table B-2.

Within and among these agencies the vast majority of the nation's larger water courses are currently under some management scheme. Implied by the research activity of these agencies is the fact that they have an expressed interest in improvement of their current forecast operations. In this effort, the USGS is extending its stream flow and precipitation gauge data telemetering activity throughout the major watersheds. Soil Conservation Service is active in the installation of telemetered snow pillow data for uncovering more point source measurements of snow depth and water equivalents.

| Agency | Primary Forecast Objective | Hydrologic Research Activity Allied to Forecasting |
|--------------------------------------|--|--|
| Bureau of Reclamation | Multipurpose reservoir operations | Weather modification gauge telemetry |
| U.S. Army Corps of Engineers | Flood Control | Gauge telemetry and data centralization snow hydrology |
| U.S. Department of Agriculture (SCS) | Water supply and Irrigation | Gauge telemetry-Snow hydrology |
| National Weather Service | Flood Warning Weather Hazard Warning | Gauge telemetry |
| U.S. Geological Survey | Supports other agencies by providing hydrologic data, etc. | Gauge telemetry and gauge measuring improvement |
| State Agencies | Multipurpose | Basin studies for specific application |

Source: Personal Communication as per reference 6.

TABLE B-2
Major Agency Research Activity Allied to Water Forecasting.

National Weather Service is engaged in automation of a real time data network for flood warning across the United States, and is involved in the use of these relay devices for a wide variety of data recorded. Bureau of Reclamation, although its greatest hydrologic research effort is to study weather modification, has recently begun to invest considerably in automation of its data recording instruments. Uniform dollar figures are hard to assign to the data telemetering activities of the various agencies because the budgeting of categories of each agency vary widely. A coordinated controlled program of data telemetry is of enough concern to all of the above agencies that they are operating together under the coordinating efforts of the Army Corps of Engineers. This effort is identified as the National Hydrometeorological Reporting Network (Hydromet) and is in various stages of development depending on where in the country one looks for the facts.^{6/} The project is intended to be operational by 1975 in the Pacific Northwest where efforts are most concentrated but nationally Hydromet is far from complete at present. From the persons contacted, however, 1980 is not a premature date to expect a nearly operational system in most of the major river basins of the conterminous United States. The methods by which these and other hydrologic data are currently applied to the more well researched basins are explicit in the discussion of forecast modeling activity.

MODELING APPLICATIONS OF FORECASTING ACTIVITY

Computer synthesis of forecast activity is a relatively new art, and long term records of operation are not common. Essentially, three major systems are in operation and the general trend reflects progressive advancement from one system to the other with increasing sophistication of the forecasting agency.

These three systems are defined as, Parametric (using statistical regression analyses), Analytic (using generalized indices of the water budget variables), and Simulation Systems, which attempt to incorporate each or as many individual hydrologic related processes in the basin as possible. The outputs of these systems are designed to produce either an event centered forecast (e.g., flood warning potential) or a continuous forecast (for such applications as seasonal or annual water supply). An example of a more developed and widely recognized model is that of the SSARR model, developed by the U.S. Army Corps of Engineers (Figure B-3 depicts the model algorithm). Focus on the procedures used by this model will assist in providing the link between satellite sensor research, capability and operational forecasting applications in the 1980's. The rate of information being currently generated by research in this area suggests, however, that considerable alteration of the inputs to the forecast variables, and probably alteration of the model algorithm will have occurred by the projected period.

Computerized model applications to future forecasting methodology is best developed through a brief review of the SSARR model operation. The SSARR model is a mathematical hydrologic model of a river basin system throughout which streamflow (runoff) can be synthesized by evaluating snowmelt and rainfall. This model divides the precipitation runoff process into three major categories; runoff, soil moisture, and evapotranspiration.

Runoff is determined by the weighted average precipitation over the entire watershed by an empirically derived relationship of soil moisture versus runoff percent. The soil moisture index, is often termed an intermediate computer variable, and unlike the runoff factor,

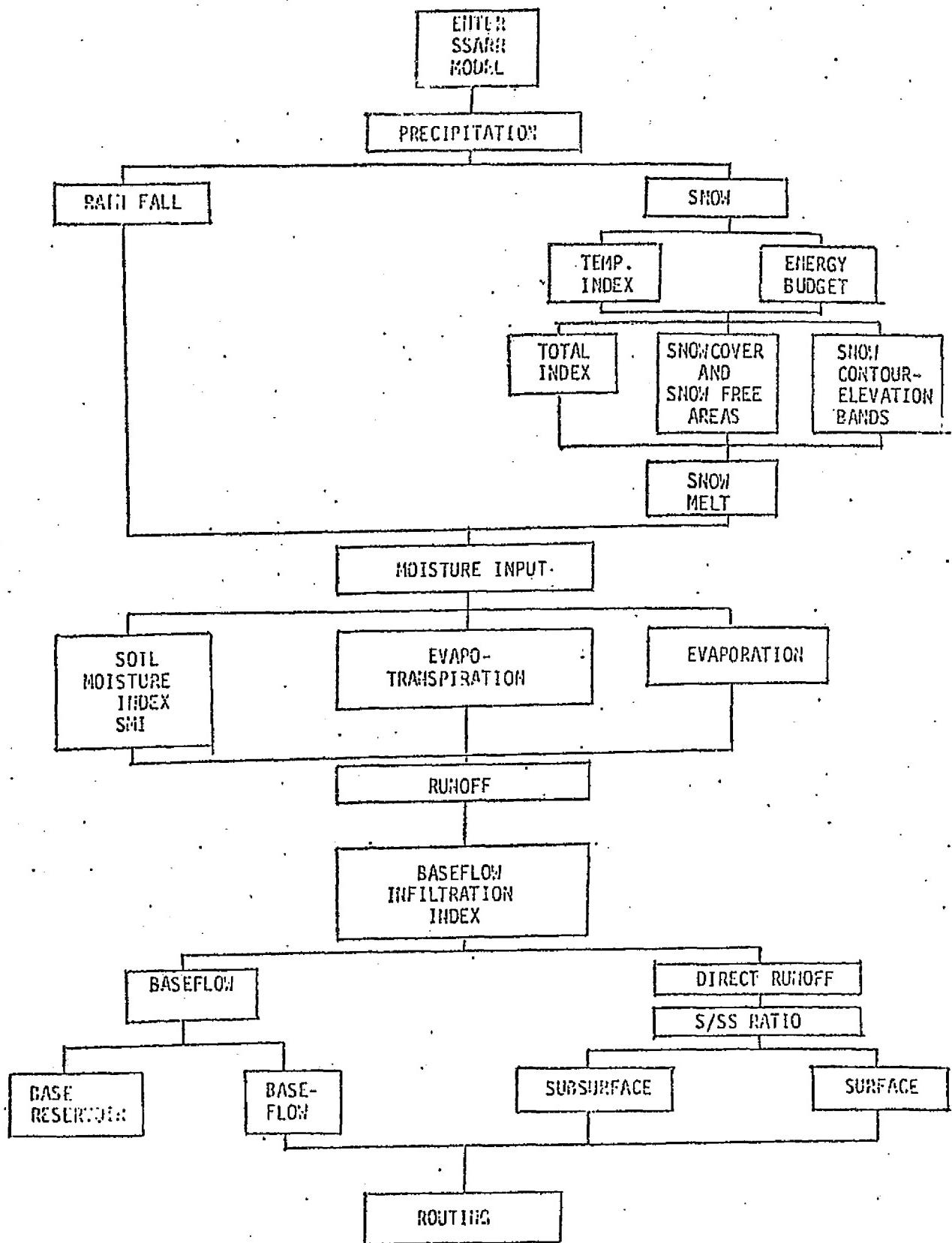


FIGURE B-3: SSARR Model Algorithm for streamflow forecasting.

it is not a direct input to this model. Instead, the soil moisture index is derived indirectly through an accounting of the precipitation, runoff and total evapotranspiration data. Evapotranspiration is a direct input variable. It is determined by a weighting and statistical manipulation of point source data. The techniques of deriving these point source data are essentially those described in a previous section.

The total generated runoff is divided into its three components: baseflow, surface flow, and subsurface flow based on pre-established (field data derived) relationships (i.e. baseflow infiltration index vs. surface input). Each of the components are then routed through a series of linear reservoirs and summed to yield the total hydrograph. Snow water equivalence data for this model incorporates the measure of snowline elevation, temperature measurements, snow extent, snowpack characteristics, snow type, and thickness in its current operation.

Several other models exist, but their delineation would not serve the objectives of this report. Because of the inherent multiplying effect to be realized by improvements in the modeling of water resources activity, the most effective advantages to future forecasting will be realized by efforts which adjust remote sensing data to the models themselves.

The potential attributes of similar models are significant since they can permit development of explicit descriptions of various hydrological processes that can now or may, in the future, be directly observable by remote sensing. This capability provides the ability for the forecast models to grow as our knowledge and accuracy of the uses of remote sensing grow.

Because of the lag between research and specified field applications found to be present in many of these agencies, it is felt that prediction of the 1980 field forecasting situation, based on present research, is not as unreliable as one might expect. (Evidence for the 1980 situation is

gathered largely from personal communication with the above mentioned forecast agencies in conjunction with past work on the water resources case study contribution to the on-going cost benefit contract.)

By 1980, the research-generated forecasting techniques will be a good deal more applied than they are at the present time. The difference or advancement, however, will incorporate more of a change in extent of the present day research technology rather than introduction of unique measurement techniques. Specifically, the use of telemetry and automatic data processing techniques will permit near real time transmission of data from most point source measurements in the basin to a centralized control station. From this station the incoming measurements will be transferred to particular computerized hydrologic models for the basin. In combining these data with historic records, the models will enable calculation of the water budget on a real time basis. On a larger scale, these data can be retransmitted from the basin center or transmitted directly to the central agency (for example, a central hydromet facility) for regional analysis. At this larger level, meteorologic information will be of significant value to the interpretation and prediction of regional hydrologic conditions.

The shortcomings of these forecasting advances will still be found in the problem of assessing the areal distribution of the water budget components on the basis of point source measurements. The accuracy of the forecast will still be limited by the accuracy of assessment of areal distribution of evapotranspiration and soil moisture in particular. Point source measurements of snow density and depth will likewise limit snow water derived runoff forecasts in the western mountainous areas.

As is implied by these projections, improvement in the assessment of areal extent of the hydrologic phenomena will become increasingly dependent upon direct areal extent measurement of the phenomena rather than upon point source measurements.

PROJECTED FORECASTING TECHNIQUES: APPLICATION OF REMOTE SENSING FOR ASSESSING AREAL EXTENT OF PHENOMENA

The point source measurement technique employs statistical analysis which is only as good as the sampling network and measurement accuracy at the sampling sites. The alternative technique of direct areal extent measurement using aircraft or satellite, however, is yet to be defined in terms of its accuracy and availability to the watershed managers. For example, the state of the art of aerial remote sensing of evapotranspiration assessment is currently possible only through knowledge of hydrometeorologic conditions in conjunction with vegetal vigor changes, neither of which have been correlated for the purpose of pinpointing their relationship to actual evapotranspiration. Aerial remote sensing by 1980 will, hopefully, be able to provide the kind of detailed information which may permit application of hydro-climatic data for a specific basin which is itself accurately identified with respect to vegetation and soils. It is the refinement of the sensing system in conjunction with more accurate measurement of other hydrologic parameters which will permit accurate identification of evapotranspiration rates and extent. To date, however, such results are not demonstrated because of the concomitant lack of defined sensor capabilities and research linking those capabilities to the actual forecast procedure on a real time basis.

Parallel to this situation is the situation for soil moisture and snow water equivalence approximation using areal extent measurements.

Soil moisture is somewhat quantifiable in those areas of little or no vegetative cover presently identified as containing greater or less than 20 percent soil moisture, on the basis of the soil reflectance and knowledge of the soil type. Much finer discrimination will accrue with the use of better sensors, more extensive delineation of soil types, and the added information concerning vegetal vigor relationships to soil moisture. As indicated, these parameters, governing soil moisture measurement, are currently under investigation. It is expected by 1980, that the assessment of the areal distribution of soil moisture will be refined.

Snow water equivalent, like evapotranspiration, is a highly perplexing phenomena to assess over any given area. Unlike evapotranspiration, however, snow water equivalence is closer to being predictable by 1980. This is so because some of the surrogate parameters which define snow water equivalent are currently being identified, and incentive for progress in this discipline is considerable (due in part, to the economic impact of improving the snow water forecast). Already demonstrated by ERTS investigators is the fact that areal extent of snowpack is directly observable to a level of accuracy equalling or exceeding conventional procedures.^{7/} Likewise, snow brightness as an indicator of ripeness or age which may suggest snow density and/or areas of snow accumulation is currently being defined by research. When these data are perfected and aligned to temperature measurements, hydrologists may have a measure of areal distribution of snow density and melt potential. Aligning these data with the historical record will aid in prediction of total snow water releases during the melt season.

A matrix which capsulizes these aspects of the current and projected 1980 hydrologic forecast procedures is shown in Table B-3. Another method of stating the situation is through a diagram of the water resource management information system Table B-4. This diagram explains only what the relation-

Table B-3 Current and Projected Forecasting Techniques.

| | Current Technique | Projected Technique |
|-----------------------|--|---|
| Snow Water Equivalent | <ul style="list-style-type: none"> • Point source measurement either surveyed on foot or by aircraft. (Most common is densitometry measurement involving the weighing of a given volume of snow either with tubular coring devices or with snow pressure measuring devices commonly identified as snow pillows.) Low flying aircraft are used to both read snow depth markers and in some cases record radio isotope point source measurements. | <ul style="list-style-type: none"> • Satellite or ground relay of telemetered radioisotope point measurements of snow water content in conjunction with satellite or aircraft monitoring of snow depth via markers. • Continual monitoring of albedo changes as an indication of new snow accumulation through the season. (Direct snow water equivalence data, not as yet available through aerial or satellite based systems but surrogate information will provide close approximation.) |
| Soil Moisture | <ul style="list-style-type: none"> • Point source measurements using electrical resistivity or manual sampling of soil involving assessment of weight difference between natural soil sample and dried sample. • Aerial remote sensing which permits distinction between saturated and dry soils in un-vegetated areas. | <ul style="list-style-type: none"> • In unvegetated areas, changes in reflectance of a given soil can be sensed and resolved to a much finer degree which permits finer soil moisture discrimination. • In vegetated areas, infrared remote sensing of changes in vegetal vigor identifies soil moisture, given index plots in which the relationships between vegetation, soil moisture and salinity types is defined. |
| Evapotranspiration | <ul style="list-style-type: none"> • Point source gauge measurement using correlation between gauge and field conditions. Data collected by field surveys. • Other measures, in areas where point source measurements are impractical, involve estimation of evapotranspiration by working back through water budget, and assigning the unaccounted water losses to evapotranspiration. • Another technique is to calculate evapotranspiration on the basis of field derived temperature humidity and wind speed as limited by the available soil moisture. | <ul style="list-style-type: none"> • Extensive telemetered network of point source measurements as described in current techniques. • Expansion and refinement of equations which calculate evapotranspiration as also described in current techniques. (Accurate direct surrogate measures of areal extent not yet devised.) |

1976-1981
1976-1981

| | | | | | | | | | | | | | | | | | | | |
|---------------------------------------|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| W.M. USGS SCS, & Other Surveys | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Aircraft (Vis & IR) as needed | 2 | 2 | 2 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| ERTS-A (visible) 200ft/12 days | 2 | 2 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 |
| River-2 (Visible-visible).33mi/12 hr. | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 3 | 1 | 1 | 3 | 1 | 1 | 1 | 1 | 1 | 1 |
| River-2 (SR-visible) 2 mi/12 hr. | 1 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 3 | 3 | 1 | 1 | 3 | 1 | 1 | 1 | 1 | 1 | 1 |
| River-2 (SR-IR) 3 mi/12 hr. | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| RTV-3S-5 (THIR) 4.3mi/12 hr. | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| RTV-3S-5 (ESMR) 15.6mi/12 hr. | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| River (Visible) .5mi/12 hr. | 1 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 3 | 3 | 1 | 1 | 3 | 1 | 1 | 1 | 1 | 1 | 1 |
| River (Thermal-IR) 2mi/12 hr. | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Satellite ATS-F (Visible) 15mi/20min | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 3 | 1 | 1 | 3 | 1 | 1 | 1 | 1 | 1 | 1 |
| Satellite ATS-F (IR) 9.6mi/20min. | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| RIMBUS-F (THIR) 4.5mi/12 hr. | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| RIMBUS-F (ESMR) 15.6mi/12 hr. | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| ERTS-B (Visible) 100ft/12 days | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 3 | 1 | 1 | 3 | 1 | 1 | 1 | 1 | 1 |
| TIERS-A (Vis.-IR) 522ft/12 hr. | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 3 | 2 | 2 | 3 | 1 | 1 | 1 | 1 | 1 | 1 |
| TIERS-B (Vis.-IR) 12 hr. | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 3 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 |

**Code A: Information Sources/
Outputs**

Blank= contribution insignificant.
(future application potential insignificant.)

1= contribution not demonstrated but promising for future applications

2= contribution significant but requires additional verification.

3= contribution substantial: requires no additional verification.

**Code B: Information Output/
Hydrologic Variable**

D=Direct input to present or planned measurement of variable.

A=Ancillary information to present or planned measurement of variable.

Table B-4

CONDITIONS:

1) The applications of these relationships imply a suitability only to areas where the effects of cloud cover, vegetation, topography, size of observed area, and rate of change and annual variability of climate are not deleterious to the sensor discrimination, and vehicle frequency of coverage. Several alterations would be required in the matrices if these variables were interposed.

2) The stated relationships reflect demonstrated but not necessarily ongoing capabilities.

Code D-Project Requirement/Management Applications.

| | | | | | |
|---|---|---|---|---|-----------------------|
| X | X | X | X | X | Total Water Supply |
| X | X | X | X | X | Recreation |
| X | X | X | X | X | Navigational |
| X | X | X | X | X | Irrigation |
| X | X | X | X | X | Hydro Power |
| X | X | X | X | X | Flood Warning |
| X | X | X | X | X | Water Quality Control |
| X | X | X | X | X | Public Works |
| X | X | X | X | X | Wildlife Management |

D

A

C

Code C: Hydrologic Variable/Project Requirements

Blank=No Relationship

1=slight relationship

2=moderate "

3=substantial "

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|-------------------------------------|---|---|---|---|---|---|---|---|---|
| D | D | I | I | A | A | A | A | A | Precipitation Total (from rain) | 3 | 1 | 1 | 1 | 2 | 3 | 3 | 1 | 1 |
| I | I | D | I | A | A | I | I | A | Snow Water Equivalence | 3 | 1 | 1 | 1 | 2 | 1 | 3 | 2 | 1 |
| A | A | I | A | A | I | D | I | D | Soil Moisture | 2 | 1 | 1 | 2 | 1 | 2 | 1 | 2 | 1 |
| A | A | I | D | I | D | I | D | I | Evapotranspiration/Sublimation | 3 | 1 | 1 | 2 | 1 | 1 | 2 | 1 | 2 |
| D | I | A | I | A | I | D | I | D | Surface Runoff (stream flow) | 2 | 1 | 1 | 3 | 1 | 2 | 3 | 2 | 1 |
| A | I | A | I | D | I | D | I | D | Interflow | 1 | 2 | 1 | 3 | 1 | 1 | 2 | 1 | 2 |
| D | A | A | A | A | I | D | I | D | Ground Water Flow | 3 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | 1 |
| I | A | A | A | A | I | D | I | D | Surface Water - Physical Dimensions | 2 | 2 | 2 | 2 | 2 | 3 | 3 | 2 | 2 |
| D | I | A | D | I | D | I | A | D | Surface Water - Sediment Load | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 1 |
| A | A | I | D | A | I | D | A | D | Water Chemistry - B.O.D. | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 1 |
| D | I | A | D | I | D | I | A | D | Water Chemistry - Dissolved Oxygen | 3 | 1 | 3 | 3 | 3 | 1 | 1 | 1 | 1 |
| D | I | A | D | I | D | I | A | A | Water Chemistry - Nitrates | 1 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 1 |
| D | I | A | D | I | D | I | A | A | Water Chemistry - Phosphates | 1 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 1 |
| D | I | A | A | I | D | I | A | A | Water Chemistry-Hardness | 1 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 1 |
| A | A | A | A | I | A | A | A | A | Water Bacterial Quality | 1 | 1 | 3 | 3 | 3 | 2 | 2 | 2 | 2 |
| A | A | A | A | I | A | A | A | A | Water Chemistry-Chlorides | 1 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 2 |

HYDROMETEOROLOGICAL SATELLITE ASSISTED WATER MANAGEMENT SYSTEMS

ships between the sources of information (collection vehicles) and the ultimate application of the forecast is.

What the diagram (Table B-4) suggests is extremely promising: what must be done to demonstrate the promise is considerably arduous. We need to:

- 1) identify the relationships of forecast variable to forecast particular emphasis on the three previously stated factors, snow water equivalence, soil moisture, and evapotranspiration. An activity such as a sensitivity analysis is necessary here.
- 2) determine the relationship (sensitivity/dependency) of surrogate information, to the forecast variable, again with emphasis in the stated areas.
- 3) apply the generated information of land to a variety of basins to test for size, terrain, climate vegetation and other effects.

To an extent, this task is somewhat underway by virtue of the already defined remote sensing limitations allied to earlier sensor systems research. A brief review of the major limitation reported in the literature is appropriate here.

Paramount to improvement of forecast accuracy by using areal remote sensing techniques is the question of sensor limitation. Pertinent to this discussion, cloud cover, forest cover, sensor resolution, (particularly spatial resolution) and frequency of coverage requirements comprise the limiting factors to monitoring of the variables previously mentioned.

CLOUD COVER

In order for current sensors on the LANDSAT-1 satellite (or for that matter, all other unclassified satellites) to record the reflectance in the visible and near infrared spectrum and radiation intensity at longer wavelengths from the surface of the earth, the line-of-sight from the sensor to the surface must not be intercepted by obscuring clouds, fog, haze, smoke, and other pollutants. Furthermore, the clear zone on the space between the clouds must have a certain minimum horizontal extent in order that pattern recognition techniques may be utilized effectively. There is a continuum of opacity or transparency ranging from thin clouds to clear sky. There is a corresponding continuum of the quality of sensor observations. Clouds superimpose returns of their own, having the effect of attenuating and scattering returns from the earth's surface. These effects produce blurring and reducing of image contrast. However, it is possible to obtain useful information from a satellite even though a weather situation might be reporting overcast conditions.^{8/} What contributes to the discrimination of cloud cover interference data from snow cover is that cloud appearance on ERTS or high altitude imagery is diagnostically unique to snow as a result of the difference in the processes which form both. Clouds vary in opacity and relative to snow are independent of the land forms which they overlie. Because of this fact, in those basins in which land forms produce less than typically unique appearance to snow forms, it would be somewhat more difficult to differentiate snow from clouds despite the availability of data on cloud interference for a given area.

Based on the above discussion, and in conjunction with demonstrated LANDSAT-1 research results, cloud cover is found to impose major limitations in the Pacific Northwest basins which drain directly to the Pacific Ocean. For reference purposes, a N-S boundary of this area would intersect Mount

Olympia and trend south to the Sacramento River Basin in Northern California. From that latitude, the boundary line would trend west to the Pacific Ocean.

Generally speaking, other areas of the United States are far less obstructed by cloud cover, however, local conditions might deviate from this impression considerably. It remains to be demonstrated by future satellite or high altitude aircraft remote sensing research.

FOREST COVER LIMITATIONS

Forest cover poses another problem in that the present sensors cannot "look" through dense canopy covers of coniferous species; hence, direct identification of soil moisture, snow cover, and snowline information is sharply limited in dense conifer forest. Although the identification of the relationship between canopy cover and soil moisture has not been fully researched, it is expected that work in this area will markedly reduce the current problems. Quantification of this effect is, at present, not possible because the density of canopy cover of the conifer forests is not yet known. However, LANDSAT - 1 experimenters have only recently generated information which may enable the future investigator to distinguish between changes in areal extent of vegetation and changes in vegetation biomass. This difference, obtained by contrasting bands 5 and 7 imagery, offers the potential to identify canopy extent and growth for forest stands of known density. The effect of this capability is not only to allow calibration of areas in which forest cover will interfere with snow cover, but also to develop base information of soil moisture and transpiration in vegetated areas. (The distribution of conifers in the western basins is shown in Figure B-4.) Although this data is not informative by itself because of the lack of density of canopy information, it does provide a guide to the probable areas where interference could occur, pending further research.

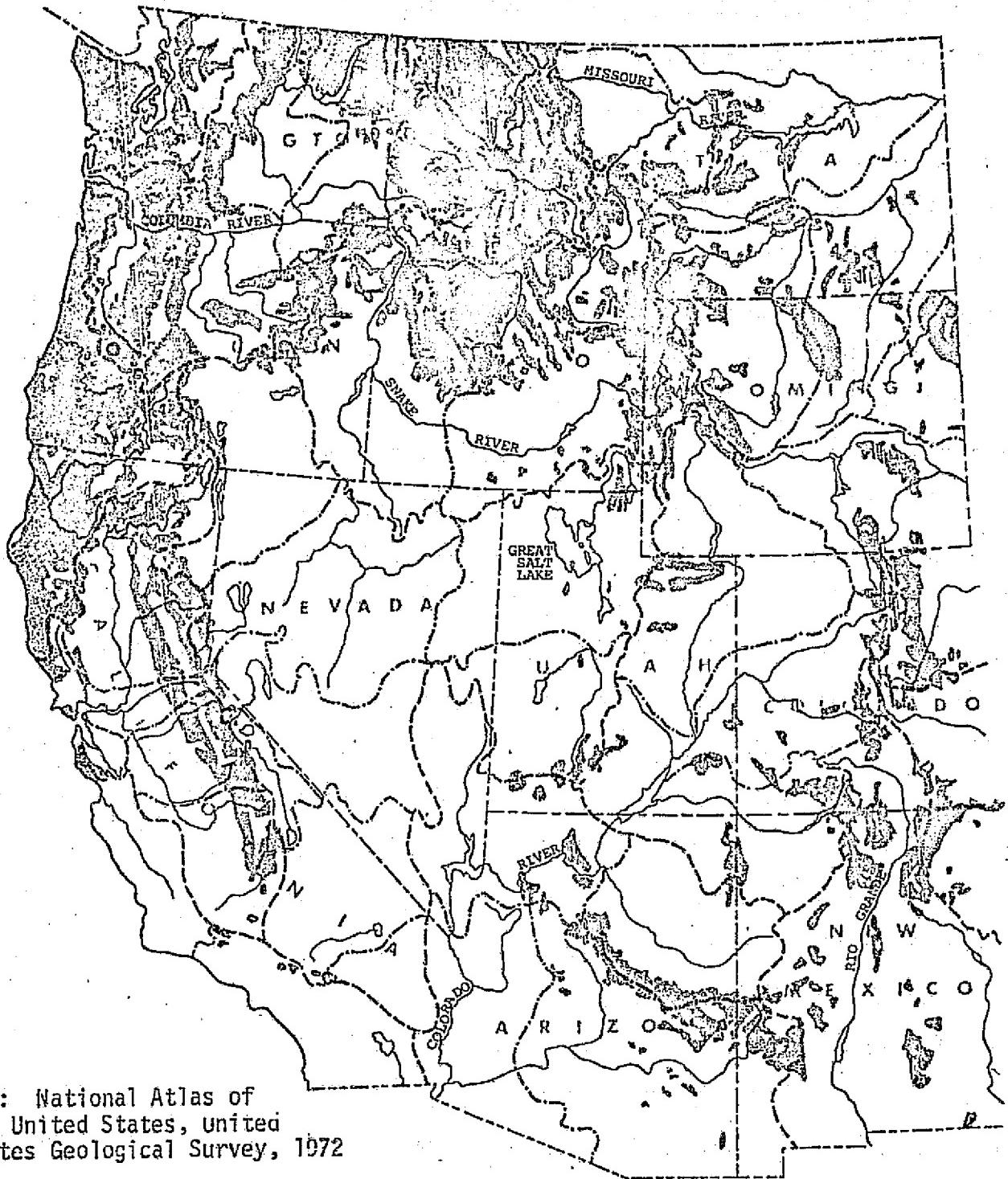


FIGURE B-4: Forest Cover Regions in the Western United States

SENSOR RESOLUTION LIMITATIONS

Sensor resolution limitations for any given sensor vary with the kind of vehicle in which they are flown and the phenomena being measured. Because the focus of this report is an error occurrence in the future, only the optimum system sensor limitations will be discussed, to the exclusion of all other systems which could be used to measure the phenomena. Current and planned weather, geological and other satellite systems as such, are not discussed here. Two limitations are implied by the term Sensor Limitations. These include spatial resolution, and spectral resolution limitations.

SPATIAL RESOLUTION FACTORS

Effective spatial resolution for the multi-spectral scanner sensor used in the LANDSAT satellite is on the order of ± 200 feet, which has proved sufficient in equaling or exceeding current aircraft in the delineation of snowline. Accordingly, areas of interest regarding snowmelt and soil moisture, are reported to be resolvable to ± 200 foot accuracy by the LANDSAT investigators. High altitude aircraft use of these sensors can narrow the resolution considerably depending on the altitude flown and the nature of the phenomena and other conditions under which it is observed.

The question of what spatial resolution is optimum is, at present, open to debate. In flat lying terrain with an unobstructed field of view where boundary delineation can be made more precisely, higher resolution is of distinct advantage. Improvements in resolution are not necessarily an advantage, however, in areas where boundary lines are not definitive and/or where the field of view is partially obstructed by the previously discussed factors. Here, less spatial resolution can be a distinct advantage in that the feature observed is interposed with the obstructions

to provide an integrated boundary line. This effect is often reported in the ERTS and NOAA research concerning snow line, in which ERTS or NOAA data is compared to that of aircraft systems. By the next decade, however, spatial resolution will have the side effect of minimizing the limitations mentioned above if the assumption is made that variable resolution imagery will be obtainable for varying conditions.

SPECTRAL RESOLUTION FACTORS

The question of what is required by improved spectral resolution is at present dependent on the definition of current capabilities which have not been fully developed. As it now stands, spectral limitations on LANDSAT are due more to the lack of a mid range IR than to deficiencies in the operational sensors for the measurement of soil moisture and evapotranspiration, as identified by vegetal vigor. However, this statement is tenous in light of recent results in band separation and contrasting used to discriminate vegetation growth types as discussed in the section of forest cover limitations.

Likewise, the capability to map snow density is suggested by some ERTS investigators to be just around the corner, but nothing other than a distinction between new snow and older snow or snow "ripeness" conditions can be made at present. Snow density assessment is still in the pure research phase of development.

FREQUENCY OF COVERAGE REQUIREMENTS

The rate at which the forecasts are updated depends on a host of factors, and it is necessary to appreciate the variety of these factors in order to establish the effect of frequency requirements on aerial remote sensing potential. Such factors as the time of year of the forecast; the forecast type, the geographic location, the type of phenomena and the rate of change of the phenomena all enter into the assessment of frequency of

coverage requirements. In the case of snow hydrologic forecasting in the western basins, the rate of snow melt during the February - July season can vary to the extent that coverage may be required from once every three weeks, to twice weekly, again depending upon basin latitude, evaluation and other factors.

A brief table showing the extremes in frequency of coverage and illustrating the variety present in the three hydrologic variables in question is shown below (Table B-5).

Table B-5

| Phenomena Critical To Forecast Accuracy | Coverage Frequency Requirement* | |
|---|--|---|
| | Minimum | Maximum |
| | Pacific Northwest basins annual fore- cast prior to melt season- February | Southwestern basins seasonal fore- casts during melt season- April |
| Evapotranspiration | Semi-monthly | weekly |
| Soil Moisture | Semi-monthly | weekly |
| Total Snow Water Equivalent (as indicated by density depth and areal extent measurements) | Semi-monthly | weekly |

*Cover frequency determined on basis of present forecasting activity in the western U.S., using current forecast records and techniques.

Source: Personal Communications as in Reference No. 8.

Coverage Frequency Extremes for Critical Forecast Variables

SOCIO-ECONOMIC FACTORS RELEVANT TO THE PROJECTED FORECAST ACTIVITY

A few economic projections shed light on the location, kind and extent of need for more accurate forecasts which will exist in the 1980's.

By 1980, the United States population will have risen to 233 million persons. The rate of this increase will be greatest in the South Pacific western regions where the population will have doubled by that time. In addition, demographic projections suggest that the largest total proportion of the population will be in the cities. To meet this growth rate, a twelvefold increase of steam electric generation and a 40% increase in irrigated agriculture will be realized by the end of the century. Other specific water demand projections are available if needed.^{10/}

The effect of imposing increased water demands in a region which is already feeling the strain on its water resources thrusts a considerable responsibility on the shoulders of the water supply forecaster. Because of the fact that the increased demands are going to be felt in an arid area, the major tasks will be those of reducing, or at least accurately accounting for, evapotranspiration and soil moisture losses to a far more accurate extent than at present. Similarly, because of the dependency of the population on snow melt releases in the southwestern basins, considerably improved forecasts of snow water equivalence will have to be developed to meet the demands of the future.

CONCLUSION

Population demography, forecast limitations using point source measurements, planned government sponsored hydrologic research basin computer modeling activity, and aerially derived remote sensing potential applications are suggestive of the greater needs of the responses to water forecasting in the coming decade.

The specific demands to be placed on the forecaster will require development and implementation of improved aerial extent measurements of

evapotranspiration, soil moisture and snow water equivalence. While the quantification of these data is not currently operational, all indications are that at least snow water equivalence and soil moisture assessment techniques will be developed. Evapotranspiration, as judged from current research, is the least likely to be quantified by aerial remote sensing technology, by the 1980's.

Interactive Computer Systems for Future Hydrological Application

The application of interactive computer systems to hydrology is being accelerated by two rapidly advancing technologies, i.e., hydrological simulation models and remote sensing. Simulation models, as previously stated, provide a "real world" mathematical view of various hydrological processes, while remote sensing offers an opportunity to monitor hydrological processes in a heretofore impossible manner. Application of these two technologies in an interactive system permits daily application of the most basic of scientific study approaches, i.e., "Observe, Predict, Observe."

NASA's Goddard Space Flight Center (GSFC) has under development an interactive information processing system which has been termed AOIPS (Atmospheric and Oceanic Information Processing System). AOIPS will permit rapid processing and manipulation of remote sensor data, ground based observational data, historical data and will furthermore permit interactive operation of available hydrological simulation models using information derived from these sources.

In order to exercise the capabilities inherent in the AOIPS and to provide an effective demonstration of its applications, we have defined a demonstration scenario which, while obviously incomplete, will permit potential users to sit at a console and operate on a set of real data in a real and complex basin.

Scenario Overview

The AOIPS hydrological demonstration scenario has been constructed in the context of existing models and data sources. An effort has been made to choose a reasonably complex simulation model which might be expected to contain most of the elements of future models and all of the elements of less complex models. The models considered for the scenario include:

- (a) The SSARR Model of the Corps of Engineers (1964)
- (b) The Sacramento RFC model (1971)
- (c) The Stanford IV model (1966)
- (d) The HEC-1 Flood Hydrograph Model of the Corps of Engineers (1973)
- (e) The Urban Storm Water Runoff "Storm" Model of the Corps of Engineers (1975)
- (f) The National Weather Service RFC Model Package (1972).

While this list is by no means an exhaustive review of model techniques, it does contain a representative sample of "operational" models.

The river forecast problem contains many of the elements which can be best served by remote sensing and interactive computer processing. The river forecast problem also includes information needs of urban flood forecasting and seasonal water runoff forecasting which are used for public disaster warning, hydroelectric power management, and related irrigation information needs.

The National Weather Service River Forecast Model Package (1972) contains a generalized description of the techniques and programs which can be used to develop operational river forecasts.

The general overview of the NWSRFS model package is presented in Figures B-5 and B-6. Figure B-5 outlines the soil moisture accounting subsystem while Figure B-6 covers the channel routing and flow routing procedures.

Data requirements for the NWSRFS model package are dynamic, i.e., meteorological and hydrological data enter the system at short (3-6 hour) time intervals. Calculations of potential evapotranspiration are prepared on a daily basis.

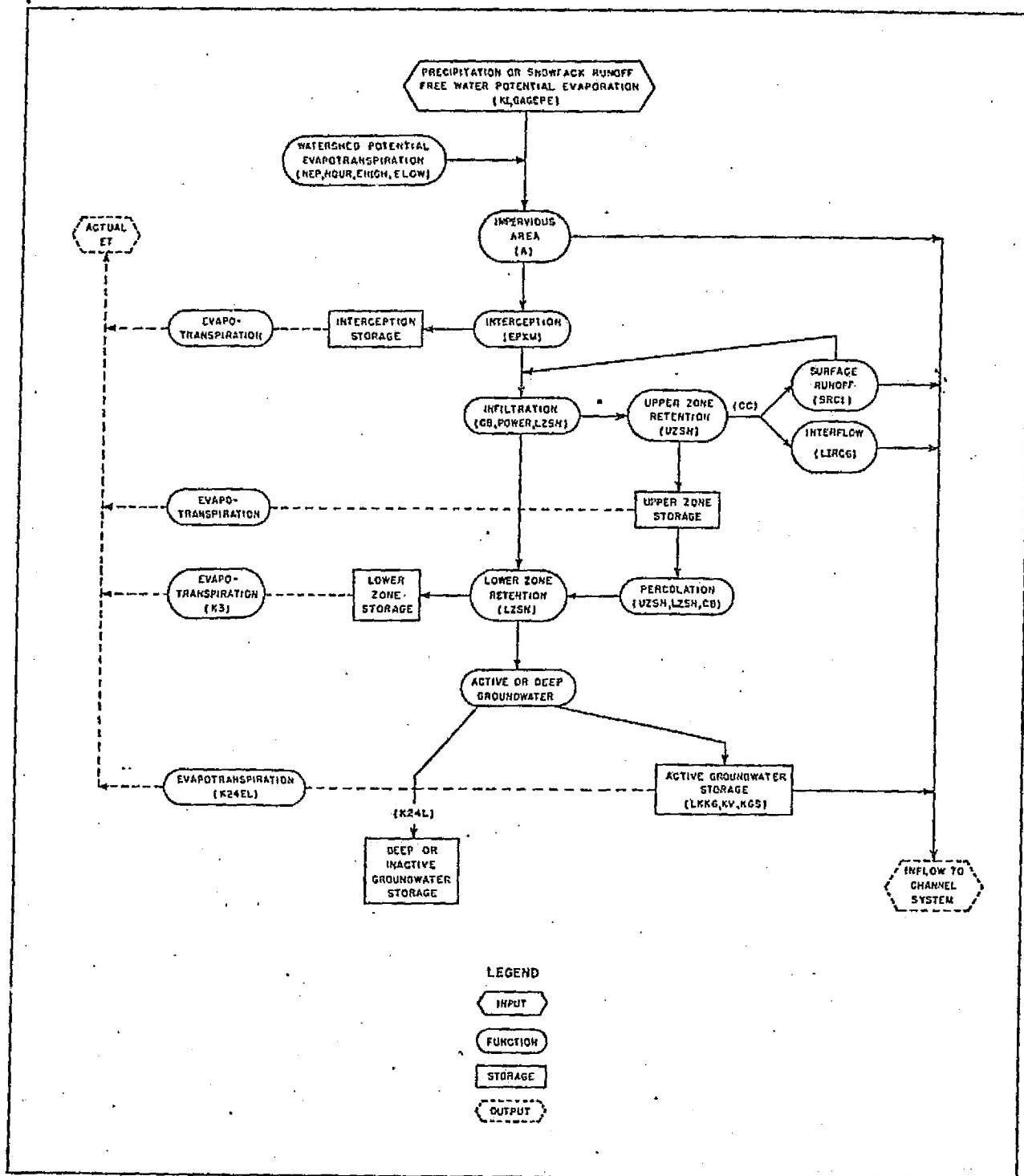


Figure B-5: Flow chart of soil moisture accounting portion of the National Weather Service River Forecasting System.

ROUTING TO PRODUCE FLOW AT A FLOWPOINT

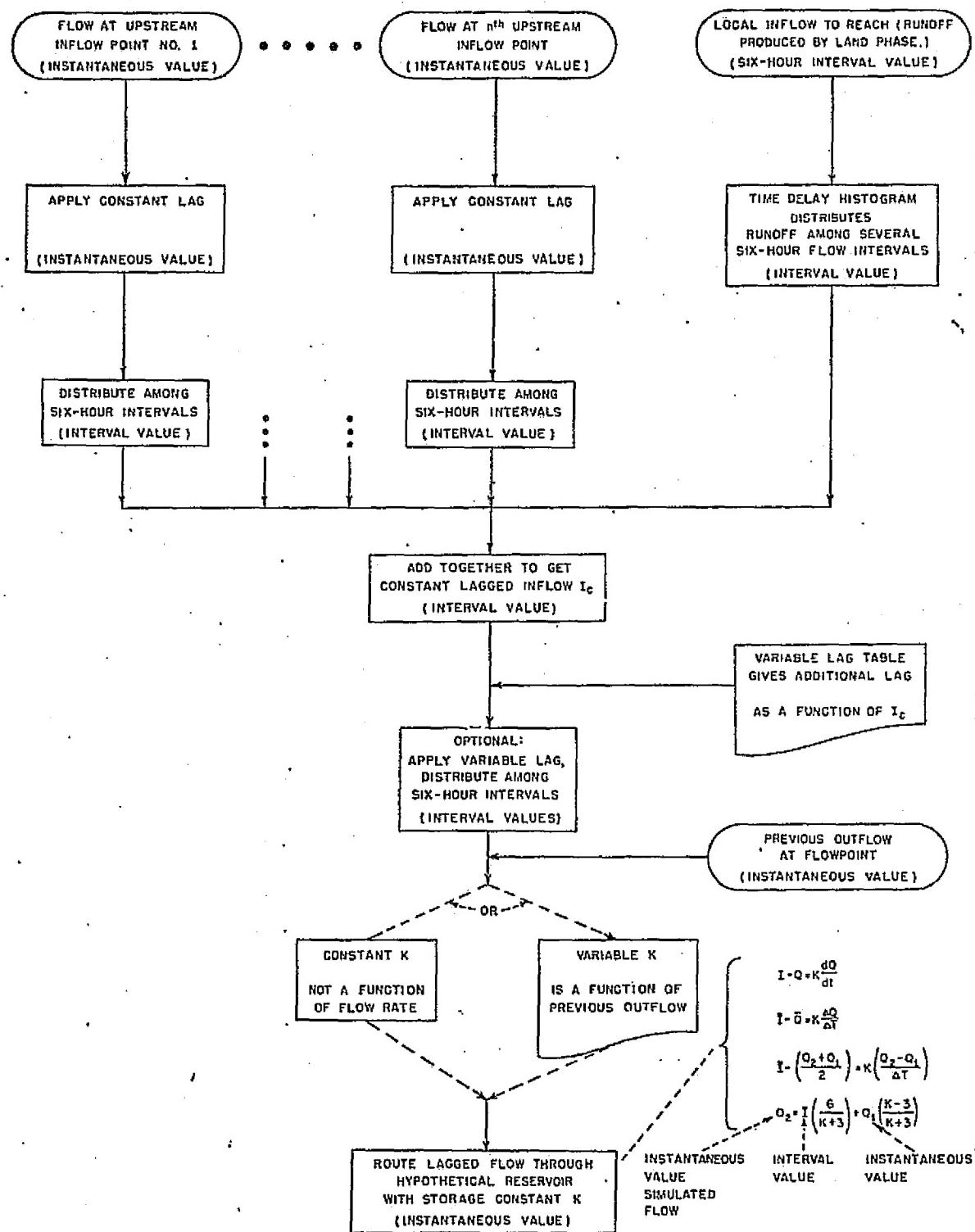


Figure B-6: Channel and Flow Routing Procedures.

Soil Moisture Accounting

The input parameters used in the NWRRFS and outlined in Figure B-5 are listed below:

- a. K1 Ratio of average areal precipitation to the precipitation input
- b. A Percent impervious area
- c. EPXM Maximum amount of interception storage (inches)
- d. UZSN Nominal upper zone storage. An index to the magnitude of upper zone capacity (inches)
- e. LZSN Nominal lower zone storage. An index to the magnitude of lower zone capacity (inches)
- f. CB Infiltration index (inches/hour)
- g. POWER Exponent in infiltration curve
- h. CC Interflow index. Determines the ratio of interflow to surface runoff
- i. K24L Percent of groundwater recharge assigned to deep percolation
- j. K3 Evaporation loss index for the lower zone (inches)
- k. GAGEPE Ratio of areal evapotranspiration to input evapotranspiration
- l. EHIGH Parameters to compute watershed potential evapotranspiration from free water potential evapotranspiration (defined in section 4.6)
- m. ELOW EHIGH and ELOW can vary for each subarea
- n. NEP NEP and NDUR are regional parameters assigned to the evaporation input station
- o. NDUR
- p. K24EL Percent of watershed stream surfaces and riparian vegetation
- q. SRC1 Percent of surface detention reaching the channel each hour

- r. LIRC6 Percent of interflow detention reaching the channel each 6 hours

$$LIRC6 = 1.0 - (IRC)^{1/4} \quad (4-1)$$

where IRC is the SWM IV daily recession constant for interflow.

- s. LKK6 Percent of groundwater storage that reaches the channel each 6 hours when KV zero

$$LKK6 = 1.0 - (KK24)^{1/4} \quad (4-2)$$

where KK24 is the SWM IV minimum observed daily groundwater recession constant.

- t. KV Weighting factor to allow variable groundwater recession rates.

NOTE: The basic 6-hour groundwater flow (GWF) equation is:

$$GWF = LKK6 \cdot (1.0 + KV \cdot GWS) \cdot SGW \quad (4-3)$$

where: GWS is the antecedent groundwater inflow index and SGW is storage in groundwater (inches).

- u. KGS Recession factor for antecedent groundwater inflow index.

Channel Routing

The conceptual distributive NWSRFS model package is not a complete simulation model in that actual stream channel characteristics are handled by a hydrological procedure termed Lag and K channel routing. This approach can be made more "real" by reducing the areas of the basin to very small units. The following paragraphs outline the channel system that is now in use.

FLOW ROUTING PROCEDURE

Lag and K channel routing, as described by Linsley, Kohler and Paulhus in Hydrology for Engineers, is used. The essence of this procedure is to: (1) introduce a time delay (lag) to account for travel time of a wave through a reach, and (2) simulate wave attenuation in the reach caused by channel storage effects. The attenuation is simulated by routing the reach inflow, suitably lagged, through a hypothetical reservoir governed by the equation:

$$\frac{ds}{dt} = I(t) - Q(t) = K \frac{dQ}{dt},$$

in which the reservoir storage constant K gives rise to the second half of the method name "lag and K." The reservoir storage is given by S, and its inflow and outflow are given by I and Q, respectively.

CONSTANT LAG

Local Runoff

In the conceptual framework of the soil moisture accounting procedure, the runoff produced in a 6-hour interval is the flow volume

delivered to the channel system in that period. The first step in channel routing is to apply a constant lag to this channel inflow. This is accomplished by the time-delay histogram. The channel system is divided into reaches which have equal travel time. Currently in NWSRFS a 6-hour time interval is used for routing computations; thus, the channel reaches have travel times that are multiples of 6 hours.

Each element of the time delay histogram is associated with a travel time zone. For example, element three is associated with a travel time between 12 and 18 hours. Each element of the time delay histogram is merely a summation of the fraction of the area contributing to all reaches with the same travel time. The total time-delay histogram is a tabulation of these summations and must equal unity.

To account for areal variation in runoff, each element of the time-delay histogram can have channel inflow from separate soil moisture accounting computations.

Upstream Flows

This value represents the time in hours for a channel wave to travel from the upstream inflow point to the reach outlet.

VARIABLE LAG

Some channel systems exhibit a lag that varies with inflow. In the NWSRFS the total lag consists of the constant lag component plus a variable component. The variable lag is applied to upstream inflows and local runoff after constant lag has been applied and after these lagged flows have been added together.

ATTENUATION BY CHANNEL STORAGE

This is the "K" part of the routing. The attenuation by channel storage is simulated by routing the lagged flow through a hypothetical reservoir with storage constant K. The reservoir inflow will have undergone both constant lag and variable lag, so let's call it I_V to distinguish it from the constant lagged flow I_C of the previous section.

The hypothetical reservoir is governed by the equation:

$$\frac{dS}{dt} = I - Q = K \frac{dQ}{dt}$$

where S is the reservoir storage, K the reservoir storage constant, and I and Q are the reservoir inflow and outflow, respectively. The above equation is exact for instantaneous value, but is used to estimate the behavior of the hypothetical reservoir over a 6-hour interval. In particular, it is used as:

$$\bar{I} - \bar{Q} = K \overline{\left(\frac{dQ}{dt} \right)}$$

This equation is not necessarily exact. \bar{I} (identically the lagged inflow I_V) is the average inflow during the period. The interval values Q and (dQ/dt) are estimated by instantaneous outflow values as:

$$\bar{Q} = (Q_2 + Q_1)/2$$

$$\overline{\left(\frac{dQ}{dt} \right)} = (Q_2 - Q_1)/\Delta t$$

Here Q_1 is the instantaneous flow at the flow point at the end of the last time period, a known quantity.

Solving for the desired instantaneous outflow at the end of the period ($\Delta t = 6$ hours) gives:

$$Q_2 = \bar{I} \left(\frac{6}{K+3} \right) + Q_1 \left(\frac{K-3}{K+3} \right)$$

For some channel reaches, the same K value is sufficient for all flow levels. Other channel reaches require K as a function of flow (variable K). As an example of the use of this curve suppose the midnight flow (Q_1) was 33,000 cfs and the average lagged inflow for the 6-hour interval midnight - 6 a.m. is computed as $I_y = 26,000$ cfs. The simulated 6 a.m. flow would be obtained as follows:

- a. Interpolate between the K vs. outflow points to obtain K:

$$K = 15.0 + (11.3-15.0) \times \frac{(33,000-30,000)}{(37,000-30,000)}$$
$$= 13.41 \text{ hours}$$

- b. Plug into routing equation

$$Q_{6 \text{ a.m.}} = 26,000 \left(\frac{6}{16.41} \right) + 33,000 \left(\frac{10.41}{16.41} \right)$$
$$= 30,440 \text{ cfs.}$$

Figure B-6 summarizes the computations of constant lag, variable lag, constant K, and variable K that have been described in the preceding sections.

NWSRFS Operations Scenario

Call Basin Archive

- (*) Soils (LANDSAT)
 - * Erosion areas
 - * Vegetation (LANDSAT)
 - Slope (roughness) (topographic charts)
- (*) Impervious areas (LANDSAT)
 - Interflow Index (historical)
 - Infiltration Index (historical)
 - Antecedent flow (prior run)
- * Albedo (LANDSAT/Metsat)
 - Ground water flow (ground observation)
- * Water area (LANDSAT/Metsat)
 - Stream flow station (location maps)
 - Constant Lag values
 - Variable Lag values
 - Constant K
 - Variable K
 - Reservoir ID

Calculate Operating Archive

- Impervious areas/basin element
- Vegetation cover/basin element
- Soil water - Holding Capacity Index
- Albedo/basin element
- Water area/basin element
- Aspect/basin element)

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

Call Basin Daily

(+) Precipitation Observations

* Satellite cloud cover

* Satellite snow cover

* Water area

Soil moisture

◦ Budget

* ◦ ESMR

(+) ◦ Ground Observations

Temperature surface (Max-Min)

* ◦ VHRR

◦ Ground Observations

(+) Dew point (surface)

◦ Ground Observations

(+) Temperature (altitude)

(+) Wind speed

* Satellite snow melt areas

* Satellite ice dam areas

* Satellite water area

(+) Stream flow/basin element

- rate

- volume

Evaporation

(+) - ground observations

(*) - satellite derived

Calculate Basin Water Status

Land Phase

Mean basin element precipitation
Mean basin element snow melt
Mean basin element snow area change (plus or minus)
Mean basin element potential evapotranspiration
Mean basin element overland flow
Mean basin element interflow
Mean basin element infiltration per zone
Mean basin element deep ground water recharge
Mean basin element active ground water storage
Mean basin element evapotranspiration per zone
Mean basin element interception
Mean basin element total evapotranspiration
Mean basin soil moisture profile end of process interval
Mean basin element inflow to channel system
Mean basin element solar radiation

Channel Phase

Per basin element inflow
Flowpoint flow

- * Indicate direct satellite derived quantities
- (*) Indicate potential satellite derived quantities
- (†) Indicate telemetry data

** The satellite-derived information can in the future be extended
to include for some areas:

- Variable lag information
- Infiltration index
- Slope (?)

FOOTNOTES

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Mr. James Ellingbore, Water Resources Section, Bureau of Reclamation; Mr. Robert Rallison, Chief Hydrologist, Soil Conservation Service; Mr. Joseph Kragwall, Water Supply Forecasting Unit, U. S. Geological Survey; Mr. Ralph Krosge, National Weather Service.
(All communication conducted solely for this report during the latter week of January 1974.)
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